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THE UNIVERSITY OF ALBERTA

HARD AS ROCK: A STUDY OF CHILDREN'S PERCEPTIONS OF MINERAL HARDNESS

by

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A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Hard As Rock: A Study of Children's Perceptions of Mineral Hardness", submitted by Mary Margaret Schoeneberger in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Elementary Education.

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ABSTRACT

This study was concerned with identifying children's perceptions of the physical property mineral hardness and of the use and application of this property by children as part of an exercise in mineral identification. The principal intent of the investigation was to examine the nature of the perceptions which children developed of the meaning of hardness within the particular context of their engagement in the study of minerals and rocks in the natural environment of their classrooms. These perceptions were revealed through and reflected by the ways in which children worked with and talked about mineral specimens.

Participant observation was identified as being the most desirable method for obtaining descriptions of daily activities. An essential tool of the research involved a careful analysis of language and behaviour in order to uncover the real meaning being present as children made the transition from the everyday commonsense meaning implied in the use of a term to its use in a precise circumscribed scientific application.

Interpretation of daily activities indicated that a discrepancy existed between the intent of the curriculum formulators and the final perceptions of the children. Throughout their study of minerals and rocks children continued to associate hardness with a notion of breaking rather than scratching, the latter being associated with a scientific understanding of the concept.

Children were observed to employ systematic strategies in their determination of mineral hardness and, although these did not

always conform to the intended strategy, they were sufficiently 'workable' to enable the children to order according to hardness a given set of minerals. An examination of the suitability of the materials chosen to convey the nature of approaches towards and the feeling for science revealed that attempts to simply concepts and techniques for children can complicate rather than simplify them.

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LIST OF SYMBOLS

FN - Fingernail

CC - Copper Coin

S - Steel

F - File

H - Hammer

SP - Streak Plate

M - Magnet

7 - Talc

40 - Halite

43 - Fluorite

4 - Apatite

28 - Corundum

◇ - Testing stage

○ - Testing step

▭ - Inferences

⬚ - Inference uncertain

□ - Conclusions; recorded in boxes ranging from Box 1, noting the softest mineral, to Box 5 noting the hardest mineral

- - - ▶ - Sequence of testing operation

——▶ - Sequence of inferences

+ - Positive test result acknowledged

- - Negative test result acknowledged ("nothing happened")

(2)X - Number of times an operation occurred

comment - Observer comment

(clarification) - Observed behaviour or clarification

---- - Short break or pause within or following an utterance

-------- - Long break or pause within or following an utterance

Chapter I

THE NATURE OF THE STUDY

The following study constitutes an investigation of the understanding children have of one specific physical property of minerals, 'hardness', and of the use and application of this property by children as part of an exercise in mineral identification. The principal intent of the investigation is to examine the nature of the perceptions which children developed of the meaning of hardness within the particular context of their engagement in the study of minerals and rocks in the natural environment of their classrooms. These perceptions as they developed are revealed through and reflected by the ways in which children worked with and talked about the mineral specimens, relevant data with respect to this being collected through in-depth participation in and observation of the daily activities of the children over an extended period of time.

An essential tool of this type of research involves careful analysis of language and behaviour as this specifically relates to the tasks in hand and to the development of concepts as these tasks evolve. In other words, the analysis of language and behaviour helps to uncover the real meaning being present as a child makes the transition from the everyday common-sense meaning implied in the use of a term (the idiom of the classroom and the vernacular), a situation generally referred to under the rubric of embeddedness of language, to the use of the term in the precise, imposed meaning of a strictly circumscribed scientific application.

The Research Questions

In an attempt to uncover the nature of the understanding which children have of the physical properties of minerals, particularly as such properties pertain to mineral identification, several questions of over-riding importance emerged which served as guidelines for the investigation. The principal question took the following form:

1. What is the nature of children's understandings regarding the physical properties of minerals, particularly as such properties relate to mineral identification?

Other questions addressed themselves to the following issues:

2. What relationship exists between the verbal description provided by the children of a given physical property and their operational use of such a property in mineral identification?

3. To what extent do the understandings of children regarding a given physical property in selected geological contexts correspond with and differ from those of adult scientists?

3(a). How do professional geologists describe and use a given physical property within the context of mineral identification?

3(b). What is the nature of the similarities and differences which exist between children and professional geologists in their description and use of a given physical property within the context of mineral identification?

With respect to the issue of children's understandings of physical properties, care must be taken to make a careful distinction between common-sense concepts and scientific concepts relating to such beliefs, distinctions which are discussed in subsequent chapters of this document. It also should be noted at this stage that it is possible to regard children's belief systems, in a sense, as the second differential of an instructional sequence. The intent of the developer of an instructional package (a curriculum unit) can be considered as the starting point, the interpretation of that intent by the teacher as the first differential and the perceptions of the children of the teacher's interpretation as the second differential within the overall sequence:

Intent --------→ Interpretation --------→ Perception

Due to the nature of this investigation, issues related to the character of the relationship between and among these components emerge and become topics for consideration within the total context of the study.

As anticipated the significant features of the study manifested themselves in the following areas:

1. An initial understanding was gained of the nature of the relationship between the manner in which children gave verbal expression to and manifested operational expression of scientific concepts and phenomena.

2. A basis for a relatively unexplored approach to the investigation of the acquisition of science concepts by children in the classroom was examined and described.

3. New methods of handling data acquired during such investigations were set out.

4. Discrepancies between the initial intent of curriculum formulators and the final perceptions of the children were described.

5. The material chosen to convey the nature of approaches towards and feeling for science were subjected to close scrutiny and their suitability examined.

An Evolving Focus of Research

The focus of this study emerged as a result of an initial evaluation of the investigation which began with a broad-based approach involving the parallel consideration of several research methodologies, and relatively large student populations. The possibility was also initially considered of examining children's perceptions not only of several mineral properties but also of their perceptions regarding rocks and fossils. Perspectives began to change as I came to the realization that a truly thorough understanding of the perceptions of the children would only begin to emerge on the basis of the detailed observation of a small number of children within the classroom setting as they attempted to grapple with the problems of understanding but one mineral property. Despite all of this narrowing and focusing, the impression persists that much research remains to be carried out before all of the factors underlying effective instruction relating to this particular physical property may be regarded as truly having moved into the realm of understanding. It is worth noting, en passant, however, that the initial broad base of investigation did yield a considerable body of data on the mineral properties 'colour' and 'lustre' as well as a significant amount of information regarding the views of the children with regard to fossils and the processes of fossilization. However, in order to present a clearer picture of the research methodology employed, as well as a thorough analysis of the data derived with respect to the property of hardness, a full consideration of these other data has been set aside temporarily and awaits other times and venues.

A Perspective of Research

Studies of this nature in particular, but all educational studies in general, have a measure of meaning and integrity only to the extent that the interest and significance of the things that participants do and say are objectively recorded, dispassionately analysed and accurately reported, the bias inherent in program, students, teachers, terminology, observer and procedure being recognized and accounted for throughout the course of the investigation. In participant observation research there exists on the part of the investigator the critical need for an awareness of such biases, an awareness which can only be achieved by constant self-analysis and a 'looking from without' at the developing study. The challenge for the investigator lies in succeeding at one and the same time to be one with the group under study while still remaining a detached observer. This can be achieved by adopting the stance referred to as 'anthropological strangeness' in which the researcher becomes sensitized to the taken-for-granted assumptions which constitute the established system of a given group, in this case a group of Grade VI children engaged in the study of mineral properties. This being recognized, emphasis is still required with respect to the point that the essential nature of the research will be misconstrued if one talks of findings rather than understandings. An understanding of what is happening in classrooms (in this particular instance with respect to concept acquisition), is of critical importance to all of us engaged in teaching, constituting an immediate and pressing reality as far as teachers and students are concerned.

In this study understanding will have been achieved to the extent that one is able to anticipate and interpret a child's perception of the concept mineral hardness as appropriately as another member of the Grade VI class also engaged in studying the Minerals and Rocks unit. In other words, the objective of understanding will have been attained to the extent to which the reader feels that upon being placed in a Grade VI class studying the Minerals and Rocks unit, he or she would be able to react in the same manner as the children with respect to the concept mineral hardness, or alternatively, would be able, from the point of view of assuming the role of teacher, to anticipate how the children might act.

Such understanding rarely, if ever, can be tapped merely by sociometric charts, questionnaires or casual interviews but is more likely to be revealed, and even then somewhat inadequately, by ongoing persistent and detailed observation and shared analyses by participants and observer-participants of events as they take place. The term observation, itself disarmingly innocuous, characterizes no single technique or approach as one examines events within the complexity of classroom interaction, the only realistic milieu from which concept acquisition, in the truest sense, can even be determined as far as the formal instruction of children is concerned.

An Emic Approach

Other forms of data acquisition, although having significance to specific facets of some types of research are to be regarded, as far as this study is concerned, as being subordinate to in-depth analysis based upon detailed observation of children and classrooms. It follows, therefore, that this study could only be conducted in a fashion conducive to the generation of significant data by the participation on the part of the investigator in the daily life of the classroom as children pursue their study of science. This task was approached by adopting an emic or insider's point of view with respect to the investigation, an approach in which the stance is taken that the children themselves provide the key to understanding. Such a perspective, common to anthropological research, views the participants as actors who actively create and construct their social world during the course of everyday activity, a social world which reflects their practical interests and common experiences (Pike, 1976; Pelto, 1970). During daily activities, meaning structures emerge and become integrated into the social setting and eventually may be shared by many of the participants in the experience. The intent of this investigation will be to reveal the nature and extent of the individual and shared meaning structures subscribed to by children with respect to mineral properties, with prime attention directed toward the property of hardness.

An emic approach to research also assumes the integral involvement of the investigator in the research setting, a situation which results in the experiential knowledge of the researcher becoming an additional topic for inquiry. A common procedure for acknowledging this involvement is to adopt a first person style of reporting, a technique which has been used from time to time in this study.

In summary then, my intent is not to give the impression that I have developed a proposition which has been verified, rather it is my aim to set out a case study of two classroom experiences, a study which involves an in-depth analysis of the perceptions of children with respect to a scientific concept and which demonstrates as far as possible, the problems, pitfalls, biases and uncertainties inherent in this type of research. The study is meant to be relevant and useful; not to be normative, but to illuminate. Given the completion of several studies of this kind, it eventually may be possible to synthesize and generate general theoretical statements which will be of wider significance than the particular statements emerging from each of the individual studies from which they were born. In the chapters which follow an attempt is made to contribute to this process.

In Chapter II literature related to the problem under investigation and to the methodology being applied is examined and the suitability of the methodology explored. Chapter III traces the development of the study through a description of three phases which yielded parameters within which the study evolved and during which a focal point became manifest. In Chapter IV the context of the study is presented; the setting for the study is described and the perspectives of the curriculum developer and the earth scientist are examined, the latter providing a descriptive framework for the examination of children's understanding of the property of mineral hardness. Empirical consideration of children's experiences with and their reaction to the study of mineral properties are described in Chapter V. In the final chapter I have provided a summary of the study by presenting conclusions and recommendations and suggestions for further research.

Chapter II

THE BACKGROUND OF THE STUDY

The purpose of this chapter is to provide a background to the area under investigation namely the discovery and understanding of children's viewpoints regarding scientific concepts. Several issues provide the foci for this examination. These include a description of research conducted in the area of children's understanding of science phenomena in general and geological phenomena in particular, and a discussion of the method and theory being applied.

Studies Related to the Problem

Numerous investigations into the world of children's thoughts have been conducted over the past half-century. Some of these studies identified the expressed interests of children while others attempted to describe children's behaviour through the use of category systems. In general, in the latter context attempts were made to classify some type of verbal response obtained during an interview situation. This procedure has been manifested especially in studies relating to science education. The development of causal reasoning in the child was pioneered by Piaget (1930), with Issacs (1930) and Haung (1943), also contributing to the field.

Children's understanding of natural phenomena became the focus for other studies in the ensuing years (Oakes, 1947; King, 1960; Inbody, 1963). Generally, such studies were of a survey nature, examining children's ideas on a number of topics ranging from the origin of geologic features to the nature of light, magnetism and electricity and, to the understanding of living organisms. In the pursuit of such goals children were asked questions about experiments covering a broad range of topics. Although such studies made significant contributions toward understanding children's thinking, they have not had much effect upon educational practice because of the fragmentary nature of the investigations. In a recent study by Erickson (1975) an attempt was made not only to describe the nature of children's ideas relating to heat phenomena but also to examine the structural relationship between them. This led Erickson to make suggestions of how such knowledge might be applied in the classroom.

In the area of science education, the physical sciences have received the greatest amount of attention with respect to concept development in young children. The biological sciences have received some, but lesser, attention from investigators, however, the earth sciences including geology, have received almost no attention (Voelker, 1973), a situation which continues to exist into the 1980's.

Children's Understanding of Geological Phenomena

Several studies dealing with concept development in geology have been identified but in these studies the focus was on examining effective methods of instruction or upon determining appropriate grade level placement.

Neussbaum and Novak (1976) designed a series of six audio-tutorial lessons to teach the concept 'Earth' to second grade students. Structured interviews were conducted with each child to determine the child's explanation of the activities. Results revealed that the lessons did not result in significant gain in children's understanding of the concept 'Earth'. It was inferred that a certain degree of cognitive readiness might be needed by children to profit from lessons relating to this concept presented audio-tutorially. In addition, the authors reasoned that the use of models representing abstractions rather than direct experience might have been too abstract for second grade children.

Ashbaugh (1964) determined the difficulty level of five geological topics — minerals, rocks, erosion, earth forces and paleontology, by means of a multiple-choice instrument for grades four through six. He concluded that concepts relating to minerals including hardness, cleavage and crystal form were understood by more pupils than any of the other concepts, even at the grade four level. Concepts relating to rocks were understood by fewer pupils than any of the other geological concepts. Difficulty indices for 40 concepts revealed that pupils not only understood more at each successive higher grade level but also that more pupils understood the concepts.

Cohen (1968) developed a series of field exercises in fluvial geology (lakes, erosion and deposition) for fifth and sixth grade students. A comparison was made of the children's understanding of the concepts before and after the experimental activities. Pre-test results indicated that the children from both grades had similar global ideas of the concept but when questions became more specific, the grade six children gave more sophisticated responses. Cohen inferred that this difference was a function of maturity. Post-tests revealed little change in children's ideas of lakes, a small change in their concepts of deposition. Cohen suggested that these results could be related to the experiential differences between children in grades five and six.

Inbody (1963) attempted to assess pre-school children's understanding of natural phenomena. Fifty kindergarten children were interviewed after seeing pictures and demonstrations related to air, water, buoyancy and electricity. The children's responses were classified by methods including such styles as verbal and physical performance other than verbal. Most children used several styles of explanation with an apparent bias toward one or two. Inbody concluded that instruction based on an adult's conception of logic is often meaningless and can lead to overgeneralization and verbalization. Consequently, "every effort should be made to take into consideration the real, not voiced understandings of the children and the way children think and reason" (p. 277).

Scriven (1968) observed that research gave little insight into how concepts were used by individuals in expressing meanings. He proceeded to analyze the three steps of concepts, structure, process, and quality, as used by fourth through ninth grade students on written explanations of scientific terms. The explanation of the terms was related to age, sex and I.Q. Results revealed that the number of different concepts used by the students increased with grade level. Although sex did not appear to influence the choice of concepts, I.Q. did. Children with high and medium I.Q.'s used fewer quality concepts than children with lower I.Q.'s. Scriven suggested that these results had implications for evaluation of student achievement. He went on to suggest that since teachers evaluate students' written work according to a pre-set standard of correctness, the kind of meanings which are 'correct' will not usually be meanings that contain a large number of quality type concepts. Consequently, it was inferred that the meanings as expressed by children with lower I.Q.'s were labelled as incorrect in the rigid context of rightness versus wrongness that is prevalent in many classrooms.

Concept Usage

Several studies related to concept use have been completed. Adler (1965) studied science concept development related to the meaning of the word 'space' among college students. She found that words, "the symbols that stand for concepts", did not necessarily have common meanings for all individuals. Adler concluded that although scores on tests measuring ability to verbalize concepts were correlated significantly with scores on tests measuring comprehension of these concepts, the ability to select a correct verbal formulation of a concept did not necessarily assure understanding of the concept. She cautioned that a teacher should not assume that a student was using a word in the same way the teacher was using it.

Other studies expressed concern about the procedures used to tap children's understanding of concepts. Jungwirth (1970) pointed out that the constructive mode of science mastery which requires a student to be actually involved in scientific enquiry (i.e., the ability to discern a problem, construct a hypothesis, interpret data, etc.) cannot be tested by the use of recognition-type items which at best test analytical understanding of someone else's contribution.

Tamir (1972) in a study involving high school biology students found that paper and pencil tests were not a sufficient means of measuring laboratory performance. He suggested that there exists a "practical mode" of performance unique to practical work that involved both manual and intellectual abilities which are in some measure distinct from those used in non-practical ways. Tamir suggested different means for evaluating the practial mode needed to be developed.

It was noted that in all of these research efforts examined, the use of concepts in the elementary school was determined through formal testing situations. None of the studies investigated concept development in an actual classroom setting. Thus, little continues to be known about the nature of science concept formation and understanding as it actually develops in the classroom, the locus of most formal science concept acquisition. The need to more adequately understand these processes is especially pressing in elementary school science where the emphasis is on activity-oriented programs in which teacher-student and student-student interaction is encouraged, and where teachers continue to infer children's science understanding and achievement from the quality of their verbal responses, the accuracy of their worksheets, and their level of performance on teacher-constructed paper and pencil tests.

Theoretical Framework of the Study

The theoretical basis for examining children's understanding of concepts used in this study has its origins in cultural anthropology which holds the view that human society is organized on the basis of a shared symbolic world. The nature of this shared knowledge, its structure and function, how it is learned and how it changes, and its relation to behaviour all are topics for investigation and controversy. Recently, more rigorous and systematic empirical investigation procedures for studying culture and cognition have gained credence. Known as ethnoscience or the New Ethnography its goal is to study "the system of knowledge and cognition typical of a given culture" (Sturtevant, 1972, p. 130). The focus of investigation is everyday life which serves as the stage for discovering an individual's own definition of a particular situation, this approach reflecting essentially an emic point of view in which the individual rather than the investigator is perceived as the source of and key to understanding. The role of the investigator is to discover the meaning which an individual or a particular group of people attach to a phenomenon.

For many proponents of the ethnoscience tradition, Goodenough, Sturtevant and Wallace being three examples, the definition of culture restricts the cultural concept to ideas, beliefs and knowledge. Behaviour, an aspect which was included in earlier definitions of culture, is excluded. In ethnoscience, culture is viewed as knowledge which is acquired by people and used by them in interpreting experience and regulating social behaviour. This knowledge which contains symbols and concepts is learned and shared. Spradley (1972) suggests that cultural knowledge and behaviour are shared in the sense that one can indicate the extent to which individuals in the same role engage in similar behaviour. It should be recognized, however, that although persons may interact in a predictable manner it does not follow necessarily that each shares the same definition of the situation. Teachers and students, for example, may engage in similar behaviour with regard to mineral identification yet the scientific definitions (concepts) involved may not be congnitively shared by everyone.

In this tradition there exists the assumption that language and communication form the basis of cultural life, the analysis of which can provide insight into the set of rules which people have and use in constructing and interpreting messages about the world (Psathas, 1972). Accordingly, concepts and rules which constitute a culture are identified through the use of ethnoscience procedures. Questioning strategies help informants sort out their experiences with cultural phenomena into category systems and the construction of taxonomies assists in the identification and portrayal of concepts.

Culture as Defined in this Study

Although the focus of this study primarily is the discovery of meaning attached to a specific concept by a group of children, I do not restrict myself to a definition of culture which is purely cognitive in nature. Such a restrictive definition would not serve this study adequately. This investigation by its very nature involves an examination of both cultural knowledge (cognition) and behavioural knowledge, thus Taylor's 1871 definition of culture continues to represent more appropriately the circumstances of this study:

> Culture .... is that complex whole which includes knowledge, beliefs, art, morals, law, customs any other capabilities and habits acquired by Man as a member of society. (p. 1)

Assumptions

Within a framework of cultural anthropology and assisted by a definition of culture which acknowledges both cognitive and behavioural knowledge, the following assumptions regarding this study are made:

1. Children's language and verbal reporting about physical properties provides insight into the conceptual principles that generate it.
2. Children's language can be analyzed to determine the set of rules that children have and use in constructing and interpreting messages about their world.
3. A set of rules exists with respect to language and can be discerned, although children's understanding of the code need not be explicit.
4. A combination of children's language and operations also provides insight into the cognitive principles that generate them.

Additional Considerations

Also included in the framework of this study is an acknowledgement of the position taken by some anthropologists and more recently sociologists that people actively construct their social world. This model perceives human beings as acting toward things on the basis of the meaning things have for them. The existence of symbols such as language help a person to interpret and give meaning to a situation or phenomenon, the implication being that action is not determined by external forces in the environment or from any truth or objectivity inherent within the situation or phenomenon. Rather, meaning is derived from a continuous process of meaning construction which is emergent and unstable in the sense that patterns and meaning are not 'rigid' but rather subject to redefinition, existing only as long as the definition continues to be confirmed by elements within the setting.

It follows, therefore, that in order to identify and examine the meaning structures which people hold for a given situation, the investigator must become involved in the setting where the action is occurring. Participant observation, which by its very nature allows the researcher to become immersed in the research setting, thus becomes a valuable and appropriate tool by which human interaction can be studied and described and the meaning of phenomena discovered.

Studies Related to the Methodology

Participant observation long has been a common methodology of anthropologists, sociologists also having applied this approach for research purposes. Only recently, however, has it been gaining credence within educational circles. Traditionally, observational studies of schools and classrooms have applied interaction analysis techniques which use observational systems to reduce the stream of classroom behaviour to small-scale units that can be easily tabulated and ultimately computated (Simon and Boyers, 1970; Travers, 1973; Dunkin and Biddle, 1974). Although such efforts have produced voluminous amounts of research, their contribution to understanding has been less than encouraging (Gage, 1971). Recently, however, greater interest has been expressed in using alternative research methodologies such as participant observation for studying the culture of schools (Wilson, 1977; West, 1977). Some studies applying anthropological methods have been used in educational research, particularly at the higher education level (Becker and Geer, 1960; Parlett, 1969), such studies generally focusing on aspects of social structure or the climate of school environments (Robinson, 1974; Warren, 1975; Lasley, 1978).

In some participant observation studies teachers are the concern of researchers. For example, Dodge (1973) explored the role of the school media specialist and Wolcott (1973) provided an ethnographic account of the life of an elementary school principal. These studies provide insight into the operations of teachers and principals in the daily life of the school. Only a few studies, however, were observed to focus primarily on students with these generally examining sociological aspects of student behaviour (Peters, 1978; Woods and Hammersley, 1977). No accounts were found which used qualitative methods to study concept development in children while they were engaged in everday classroom activities. Although the study of culture and cognition has been a subject of anthropological research for some time (Goodenough, 1971; Spradley, 1972) this has not been the case in education and only recently science education researchers have begun calling for studies which utilize non-traditional methodologies for examining science concept development (Yager, 1978).

Participant Observation Procedures

Participant observation is characterized by a number of distinct features. Schwartz and Schwartz (1955) define it as "a process in which the observer's presence in a social situation is maintained for the purposes of scientific investigation" (p. 344). It is a process in which the observer becomes immersed in the 'new culture' in a face-to-face relationship with the observed and gathers data by participating in the daily life of the group, generally over an extended period of time. During this time the observer not only observes but talks with participants who are regarded as informants rather than subjects. No strong distinction is made between the observer and the observed. As part of the context being observed the observer both modifies and is modified by the context of the situation. As Gussow (1964) explains:

> When the observers are physically present and physically approachable the concept of the observer as nonparticipant though sociologically correct is psychologically misleading. (p. 240)

Gaining Entry and Establishing Rapport

Practitioners of ethnographic research have long recognized the importance of entry as a crucial element in participant observation (Viditch, 1955; Schatzman and Strauss, 1973; Geer, 1974). Based on the assumption that what people say and do is consciously and unconsciously shaped by the social situation, the observer must be extremely sensitive to the way he or she enters a setting (Wilson, 1977). Entry procedures need to be carefully initiated, firmly established and the trust of the group to be studied successfully gained in order that the research may proceed in a proper and productive fashion. To accomplish the latter, the researcher gives special attention to establishing rapport with informants in order to gain their confidence and to build a trusting relationship. It is through trusting that informants are willing to share intimate thoughts with the observer and to answer endless questions honestly and openly, conditions crucial to obtaining data that is valid. An observer also is sensitive to data recording techniques which may interfere with a trusting relationship, discontinuing their use if need be. This is particularly true in the case of on-site note taking or when mechanical recording devices are used.

Establishing a Role

In participant observation it is imperative for the observer to establish a role which will facilitate the collection of data, Gold (1969) describes the role taking process in the following manner:

> Every field work role is at once a social interaction device for securing information for scientific purposes and a set of behaviours in which an observer's self is involved. While playing a field work role and attempting to take the role of an informant, the field observer often attempts to master hitherto strange or only generally understood universes of discourse relating to many attitudes and behaviours. He continually introspects, raising endless questions about the informant and the developing field relationship, with a view to playing the field work role as succcessfully as possible. A sociological assumption here is that the more successful the field worker is in playing his role, the more successful he must be in taking the informant's role. Success in both role-taking and role-playing requires success in blending the demands of self-expression and self-integrity with the demands of the role. (p. 31)

The role of the participant observer has been discussed frequently by researchers often being described as either formal, informal, revealed or concealed (Schwartz and Schwartz, 1955; Becker and Geer, 1960; Gold, 1969). Gold incorporates these ideas in his description of four types of roles which might be adopted by a field researcher — the complete participant, the participant-as-observer, the observer-as-participant and the complete observer.

As a complete participant the researcher becomes a full participant in the on-going activities of the group, keeping identity and purpose hidden from the participants. In the role of participant-as-observer the investigator is known to everyone, being present in the situation as a scientific investigator. Participation occurs by virtue of being present in the setting while observation occurs by being allowed to do the things observers do rather than being expected to perform as do others in the situation (Wolcott, 1973). The participant-as-observer strives to develop a dynamic tension between the subjective role of participant and the more objective role of observer such that he or she never becomes completely one or the other. In adopting an observer-as-participant stance the researcher assumes a more formal observation role in which contact with participants is restricted, generally brief, and consequently often superficial. As a complete observer a researcher has no social interaction with participants opting instead to remain physically outside the situation, as occurs for example, when participants are observed behing a one-way mirror. For purposes of this study the role of participant-as-observer was adopted, the details of which are described in a later chapter.

Data and its Collection

A classroom commonly is recognized to represent a complex cultural setting (Rosenshine and Furst, 1973; Dunkin and Biddle, 1974). Because this setting is not well understood, it is useful to take into account as much of its complexity as possible, particularly during initial research activities (Becker and Geer, 1960; Dunkin and Biddle, 1974). In experimental research the relationship between two or more classroom variables is studied under a specified set of conditions in the hope of producing a proposition about relationships. Such propositions avoid taking into account the unique characteristics of any given case or individual. The very characteristics which are controlled or considered irrelevant to the problem may, however, provide important clues to understanding the nature of the situation and thus should not be overlooked. Participant observation research aims to discover 'problems' and to examine the unique situation, objectives which are accomplished by applying a variety of data collection techniques which, quite unlike those peculiar to the traditional psychometric paradigm, are characteristically unstructured. As Becker and Geer, (1960) state:

> Research aimed at discovering problems and hypotheses requires a data-gathering technique that maximizes the possibility of such discovery. Obviously, the more structured a technique, the less likely the researcher is to find facts whose existence he had not previously considered or to develop hypotheses he had not formulated when he began his study. (p.268)

The number and kind of unstructured data collection techniques available to the field researcher are many and varied. Descriptive data is collected of participant's verbalizations and behaviours, and of objects, events and settings; reactions, attitudes, routine practices and apparent trends are noted, all of these usually being recorded by means of note-taking or with the aid of a recording device. Unobstructive measures such as perusal of files, written records and archival material also may be utilized. The primary tool of the researcher, however, is the unstructured interview, the assumption being that an informant questioned in an unstructured interview situation is more likely to provoke discovery by saying something unexpected than is a respondent who must answer only specific predetermined questions or who must check only one of several precoded responses to a questionnaire item. In the latter situation it is impossible to seek clarification and, indeed, the respondent may not find his or her 'real' answer among the possibilities listed. In general then, unstructured methods, those which maximize the possibility of coming upon unexpected data, are considered basic to the discovery of meaning and understanding.

As data accumulates the researcher inspects it continually being alert to emerging patterns which form the basis of themes or propositions, themselves 'grounded' in the data. Careful coding of data into categories, the search for negative cases, and continually returning to collect more data to substantiate or delimit propositions ultimately results in the construction of theories (Glasser and Strauss, 1960).

Establishing Validity and Reliability

Within this approach, careful consideration is given to issues of validity and reliability. The naturalness of the setting is maximized by observing unsolicited events and conversations of the participants who are allowed to remain engrossed in their everyday activities. Multiple indicators of patterns are sought and propositions are verified by constantly returning to the field to recheck them with informants. In addition, the researcher is in a good position to triangulate multiple methods of observation, interviews, conversations and records (Webb, et al., 1966).

Although it is unlikely that a sample will be specified beforehand, the researcher can apply theoretical sampling (Glasser and Strauss, 1960), and is careful to describe the population, and the sampling after it has been done. In addition, a conscious effort is made to identify any negative cases which might refute or modify propositions. In this way limits of applicability of emerging theories over time, space and people can be established (West, 1977).

Problem Identification

No agreement has been reached by investigators involved in qualitative research regarding the degree to which there should be _a_ problem, _some_ problem or _no_ problem that initially guides the observer (Kraft, 1974). Generally, however,

> the person doing such research assumes that he does not know enough before beginning his study to identify relevant problems and hypotheses in the organization chosen for study nor to recognize valid indicators of the theoretical variables in which he is interested. He believes that a major part of his research must consist of finding out what problems can be best studied in this organization, what hypotheses will be fruitful and worth pursuing and what observations will best serve him as an indicator of such phenomena. (Becker and Geer, 1960, p. 268)

A half century ago Malinowski suggested the existence of 'foreshadowed problems' in approaching the study of cultural settings. He distinguishes between foreshadowed problems and preconceived solutions in the following manner:

> Good training in theory, and acquaintance with its latest results, is not identical with being burdened with "preconceived ideas." If a man sets out on a expedition, determined to prove certain hypotheses, if he is incapable

> of changing his views constantly and casting them off ungrudgingly under the pressure of evidence, needless to say his work will be worthless. But the more problems he brings with him into the field, the more he is in the habit of molding his theories according to facts, and of seeing facts in their bearing upon theory, the better he is equipped for the work. Preconceived ideas are pernicious in any scientific work, but foreshadowed problems are the main endowment of a scientific thinker, and these problems are first revealed to the observer by his theoretical studies. (1922, p. 8-9)

Smith (1967) suggests that foreshadowed problems are "those knotty questions, the toughest ones you ask the data" (p. 218). These are the questions which selectively guide the researcher's inquiry in the field. In this study, for example, some of these questions took the following form: How do children view the formation of rocks and fossils? Do children of all ages view these processes in the same way? What interests them about rocks and fossils? How do they handle the specimens? As children interacted with the materials I observed their behaviour and listened to their conversations, looked for clues and gained insight, a process which led to further questions: What does the term 'mineral' mean to a child? What do children understand by 'physical property'? How do they determine these? How do they understand and use a hardness table? What do children do which illustrates their understanding of these concepts? Throughout the investigation aspects of foreshadowed problems kept surfacing in the form of insight, guesses, hunches and clues, all of which were noted and some of which became base line or key concepts for guiding the analysis. For instance, I puzzled over aspects of the children's mineral-hardness testing procedures, the ensuing difficulties they experienced and the frustrations they incurred, about geologists' approaches to similar tasks; about 'scientific' concepts regarding mineral hardness and means for determining them, and asked myself: How do the children's viewpoints and the scientific viewpoint compare? Such processes eventually led to the formulation of propositional statements (grounded theory) which were supported by data about concept understanding as manifested in the classroom setting (Note: grounded theory - the systematic discovery of substantive theories within the data obtained as described by Glasser and Strauss (1967), the sense in which theory is being used in this study).

Advantages and Limitations of the Methodology

Potential advantages and limitations of field inquiry applying primarily observation and interviewing techniques have been discussed by Dean, Eichhorn and Dean (1969) and Schwartz and Schwartz (1955). Their observations relate to two main characteristics of such techniques, these being the unstructured nature of the inquiry and the effective use of the relationship established between researcher and informant for purposes of eliciting data. The major advantages can be summarized as follows.

1. The researcher is not bound to problems defined a priori, rather, the opportunity exists to formulate questions as the research proceeds, gradually narrowing the range of questions to those of greatest significance.

2. Not being bound by preconceived category and analysis systems allows the researcher to modify these in order to make them more suitably fit the data. Consequently, there is less of a commitment to 'junk' which can be discarded if it is discovered that a wrong path has been taken.

3. Long term on-site participation and close contact with the group under study enable the observer to study a situation in-depth and to examine variables which are difficult to quantify or which may be, at best, distorted through survey questionnaires.

4. The researcher usually is free to move back and forth between data gathering on-site and analysis off-site, a situation which allows the inquiry to be structured as the investigation proceeds and modified as new and significant data are discovered.

5. Mobility within the research setting enables the investigator to collect a variety of data which appear pertinent to the problem under investigation.

6. By living the event under study the observer is liable to identify meaningless questions more easily and can redirect the approach such that questions of greater import can be explored.

7. Participation in a setting over an extended period of time also enables the researcher to better understand the language of the culture under study and to decipher the idiosyncracies of behaviour, factors which are crucial to getting at the true meaning of events.

Several possible limitations of this methodology also have been suggested by the same authors:

1. Due to its unstructured nature and the non-standardized manner in which data are collected it generally is not possible to submit the data to rigorous statistical analysis although

quasi-statistical treatment may be made.

2. The researcher is the research instrument; thus, there exists the possibility and, indeed the probability, of bias being introduced into research activities. Although biases can be minimized and altered by an awareness of them on the part of the researcher and by making these biases known publicly through reporting them, it is not possible for all biases to be known, a situation, however, not uncommon to all types of research.

3. The realiability of the research instrument depends heavily on the investigator's powers of observation and acuity of perception. Although inter-judge reliability checks sometimes are applied, often they are not possible (as is the case with this study) and, thus, the researcher must depend on his or her integrity and experience in attesting reliability.

4. Because much of the research process depends upon participant involvement, the likelihood of their biases affecting the data also exists. This situation can be guarded against by comparing and evaluating informant statements from a variety of perspectives and in different situations, by crosschecking the words of informants with their behaviour, and by establishing why informants said the things they said.

5. Extended contact with informants over long periods of time may result in a loss of confidence in the researcher, a situation which may necessitate the abandonment of the project. On the other extreme, the researcher may become so involved in the life and events of the group under study that objectivity is lost, a situation commonly referred to as 'going native'.

The foregoing examination of literature related to geological concept development suggests that a great deal more needs to be done in the area before an adequate understanding of children's beliefs are known thoroughly. It also suggests that alternative methods for studying this problem might be explored, participant observation being one example. The chapters which follow attempt to add to this knowledge through the employment of participant observation techniques. Circumstances surrounding the decision to employ a field research strategy will be discussed in Chapter III while the scientific concepts specifically associated with the study are discussed in Chapter IV.

In reading this thesis it must be kept in mind that the process being described did not occur in a straight-forward linear fashion. Although the format of reporting might suggest this, the sequence of events, as they are described, do not necessarily represent the order in which they occurred. Consequently, each chapter must be viewed within the total context of the study. The entire process was a dynamic one and its value lies not only in the conclusions reached but also in the process by which the research was conducted.

Chapter III

THE DEVELOPMENT OF THE STUDY

In this chapter I trace the development of the study which, for purposes of clarity and convenience, is described in three phases. Tracing the events and considerations which led up to and molded the research questions is considered appropriate and important to understanding the overall context of the study.

Phase I

Preliminary Work

The initiation of this study was influenced by my interest in the manner in which children acquired an understanding of concepts in science, how they learned science that is, coupled with my personal interest in the area of geology. A review of the literature quickly indicated that little research had been conducted in the area of children's understanding of geological concepts, this omission being particularly the case with respect to those concepts formally presented to children during their elementary school experience. A survey of provincially approved textbook series (Concepts In Science, Science a Modern Approach, Science For Tomorrow's World) then revealed that two broad geological topics, rocks and fossils, commonly provided one focus of attention during the elementary school years. As a result, I began to pursue, in a broad context, children's understanding of these specific geological concepts.

Since the most important source of information about children's understanding of geological concepts would be the children themselves, certain issues presented themselves for immediate attention before work with the children began. These issues involved decisions relating to the specific concepts to be explored in the course of the study together with the identification of appropriate methods of obtaining information from the children. In contrast with the study of children's understanding of physical science concepts such as electricity or heat, in which it is possible to have children observe, interact with and respond to phenomena as they actually occur, it is impossible with the earth sciences to devise 'hands on' experiences which allow children to witness geological processes such as rock and fossil formation or mountain building as these actually take place. The vast spans of time involved and the gigantic scale on which such events occur preclude their duplication (or replication) in the laboratory. Because of these constraints, standard classroom teaching procedures often include the presentation of earth science concepts through the use of simulation exercises, analogies, pictures and diagrams. Although such methods may provide reasonable approximation for the purposes of classroom instruction, none of them seemed appropriate for use in this investigation because of the additional variables which they might introduce into the study, the aim of which was to gain a better understanding of the children's grasp of geological concepts rather than to test their ability to deal with analogies as a means of concept acquisition.

In addition to the concern for dealing with actual phenomena I also was concerned with the need to utilize natural materials as part of any planned activities, this being perhaps, a reflection of my personal predisposition developed through my teaching experience, towards keeping science learning activities for young children embedded as closely as possible in reality. Although a similar concern has been expressed by researchers in the area of biological sciences, only a few concept development studies were located which actually examined the response of children in situations involving the manipulation of actual plant and animal materials (Gillispie, 1972; Askham, 1976). In the earth science area, only an investigation by Cohen (1968) required children to react to natural phenomena. It was noted, however, that although natural phenomena formed the basis of the activities relating to all of these studies, the understandings which the children had of these phenomena were ascertained through the agency of paper and pencil tests.

The limited amount of published research in this area did not reveal any clues or suggest solutions to the problem of identifying natural phenomena which might serve as the basis of geological investigations. It was decided, therefore, to start with an examination of the observable interaction between children and natural materials, in this case collections of rocks and fossils.

Piaget (1929, 1930) suggested that something could be learned about the levels of understanding which the children had of natural phenomena by listening to the manner in which they talked about them. Accordingly, it was decided to employ a similar approach as a starting point for the study. It was anticipated that this activity might suggest directions for further study including the resolution of several procedural questions:

1. In situations in which actual experimental activities are not involved, what information, if any, can be obtained from children's discussions about geological phenomena?

2. What groups of children would be most appropriate for inclusion in such a study?

3. What unanticipated outcomes might emerge from the use of open-ended activities?

Conducting the Interviews

In an attempt to answer such questions, individual interviews designed to explore the thoughts of children with respect to two broad geological topics, rocks and fossils, were conducted with 13 children ranging in age from six to fifteen years old during the summer of 1976. Each interview was divided into two parts of approximately 30 minutes each. During the first part of the interview children were presented with a collection of igneous, sedimentary, and metamorphic rock samples, a variety of mineral specimens and several different pieces of brick and cement, the latter being included in order to ascertain the ability of the children to differentiate between natural and artificial materials. The second part of the interview was similar to the first except that a collection of fossils was used as the basis for discussion. A plaster cast of an organism was placed with the fossils, this being included in order to ascertain if the children were able to recognize a 'true' fossil (see Appendix B).

The interviews were intentionally nonstructured, allowing for an exploration of a broad range of topics. This approach also permitted the interviewer (myself) to gain experience in the use of various questioning techniques, and allowed for the investigation of the efficiency of using natural materials as a basis for discussion. All interviews were audio-taped, ongoing notes were made of each child's manipulation of the rocks and fossils, and transcripts were produced for evaluation. Selected interviews with three children, Curt, David and Paul, whose responses were typical of other children at three different age levels, are presented in Appendix C.

Observations of Phase I

The following observations evolved from the initial interviews:

1. Some geological concepts appeared to be developmental, ranging from everyday, common-sense to modern scientific.

This observation was illustrated by explanations given by the children of the mode of rock and fossil formation. Younger children often invoked some manner of outside intervention, frequently human, as being involved in the rock/fossil formation process, while older children moved away from this interventionist position toward one involving natural processes.

In the following examples, the remarks appended to each transcript excerpt refer not only to that excerpt but to the total interview with the student. For instance, Patrick (6 years, 8 months) volunteered little explanation of how rocks or fossils were formed. He focused primarily on the physical attributes of these materials particularly colour, shape, smell, malleability and attractiveness. The few explanations given for rock/fossil formation included an aspect of human or animal intervention.

Patrick: (Upon picking up a sample of iron pyrites) I know what this is for sure.

Interviewer: What's that one?

Patrick: Fool's gold?

Interviewer: You were telling me about that before. Where does fool's gold come from?

Patrick: I don't know -------- It comes from the ground.

Interviewer: How did it get there?

Patrick: I don't know ---- people bury it.

Connection between idea of fool's gold and trickery

Interviewer: Why would they do that?

Patrick: To trick some people.

Curt's (8 years, 1 month) personal theory of rock and fossil formation appeared to be primarily interventionist, with people, dinosaurs and other rocks being involved in the process. When pressed for other explanations, he drew upon his book knowledge and was able to suggest the involvement of some natural processes as the following excerpt illustrates:

Curt: (In discussing the manner in which a rounded pebble got its shape.)

Interviewer: How do you think it got to be that shape?

Curt: I don't know. Maybe it got kind of crushed by something. It might have been a roundish rock like this one (another pebble).

Interviewer: And it sort of got crushed?

Curt: Yah.

Interviewer: Supposing we crushed this rock. What would the pieces be like?

Human intervention as agency

Curt: Little pieces that were sharp. Maybe this was flattened and not crushed. Maybe it could have still been forming and maybe somebody took some mud and shaped it up and let it form.

The intervention theory then occurred in another context.

Interviewer: Where do rocks come from?

Curt: Underground.

Interviewer: How do they get there?

Animal intervention

Curt: Well, they probably formed sometimes around the ages of the dinosaurs. Maybe there were great big hunks of rocks and dinosaurs when they stepped on them -------- some of the great big ones crushed into pieces.

Interviewer: And what happened to the pieces?

Curt: Well --------

Interviewer: Could these rocks have been some of the pieces the dinosaurs broke up?

Curt: Yah.

Interviewer: That's an interesting theory. How do you think the rock in the mountains was formed?

Mentions natural processes; learned response vs real belief?

Curt: Maybe it was all mud once and formed into rocks. That's how fossils are made. And you know from the dinosaurs ages when the fish died there were only their skulls and they sunk into the mud and made a print. And later it formed into rock.

Interviewer: And how does it get harder and harder?

Curt: I don't know, but I read it in a book.

David (10 years, 6 months) was interested in rocks as a hobby and said he read a lot about them. His explanations were superficial from the scientific point of view and involved only natural processes in a vague and general way.

David: (Upon examining a piece of quartz.)

Interviewer: Any idea how it was formed?

David: From heat like a volcano.

Interviewer: What would the heat have to do with it?

David: Well, it melts all the rocks and they all form together like that.

Book information but vague true understanding of concepts involved

(Later when examining a piece of conglomerate.)

This is a sort of concretion thing.

Interviewer: What makes you say that?

David: You can see a whole bunch of different rocks cemented together.

Interviewer: What would be the thing that cements them together?

David: A kind of natural cement ---- like sand and water.

Interviewer: I see. How would those little stones get caught up in there?

David: They might be somewhere in the dirt or by the beach and they just do that.

Margie (12 years, 8 months) had never studied formally about rocks but had gained some personal experience with them through travel, play and books. Her brief superficial explanations included reference to both natural processes and outside intervention as involved in rock and fossil formation.

Margie: (During discussion of the fossil collection.)

Interviewer: What makes something a fossil?

Margie: It gets pressed in there.

Interviewer: How does that happen?

Margie: I don't know.

Interviewer: Any idea how this (fossil fern) was formed?

Poor understanding of fossilization process with interventionist elements

Margie: A leaf or plant fell on it.

Interviewer: What did it fall on?

Margie: This -------- (the rock).

Interviewer: This hard part?

Margie: Or this fell on that (rock on leaf).

Interviewer: If a leaf outside fell on a hard rock like this would it make a mark?

Margie: If it was there long enough.

Interviewer: How would it get into the hard stuff?

Margie: It would have to get pressed on.

Interviewer: What would do the pressing?

Margie: A bigger rock could fall on it.

Paul (15 years, 0 months) had studied some earth science in school, this being reflected in many of his responses. He gave more sophisticated answers to questions regarding rock and fossil formation and his explanations involved fairly accurate use of appropriate terminology.

	Paul:	(During the discussion Paul spontaneously used terms like sedimentary and igneous rocks and then proceeded to give a description of the process involved in igneous rock formation.)
	Interviewer:	How do you think the white things (crystals in porphyry) got in there?
Sedimentation; pressure involved	Paul:	Probably some loose gravel and mud compacted.
	Interviewer:	Any other way it could be formed besides compaction?
	Paul:	Igneous rocks.
	Interviewer:	How do they form?
	Paul:	Heat.
	Interviewer:	What does heat have to do with it?
Describing metamorphic processes	Paul:	Well, melts it and then solidifies it again and crystallizes.
	(This led to a discussion of crystals with Paul suggesting that the white 'things' might be crystals and that the porphyry originally might have been a liquid.)	
	Interviewer:	How would you get the crystals out of the liquid?
Giving a fair general idea of rock forming process with minor misconceptions	Paul:	Cool down.
	Interviewer:	Would these both cool down at the same rate?
	Paul:	The white stuff probably cooled down slower than the black stuff.
	Interviewer:	What makes you say that?
	Paul:	Well, the slower the thing cools, the larger the crystals.

(And, later in the conversation Paul suggested how sandstone might have formed.)

Interviewer: How would you describe 120 (red and white banded pebble)?

Paul: Sandstone or something.

Interviewer: How did the layers get on there?

Paul: The sand was compressed. The layers built up gradually.

(Later, the two rock formation processes are reiterated.)

Interviewer: What makes something a rock?

Paul: The way it was formed.

Interviewer: What do you mean, "The way it was formed"?

Paul: Well, sedimentary rocks are compressed sand and igneous rocks are heated and crystallized.

As the children progressed in age and experience they appeared to move along a continuum from a primarily interventionist position toward one which involved natural processes. Although a study of concept development across formative years appeared interesting and promising, the lack of available activities involving natural geological phenomena mitigated against pursuing this line any further at this time.

2. Ten and eleven year old children displayed a range of geological concept development and appeared to constitute a potentially suitable group for participation in geological oriented interview situations which required extensive verbalization.

It was noted that children up to the age of ten tended to give shorter and less sophisticated responses than older children, Barry and Sarah typifying the situation:

With Barry (8 years, 0 months)

Interviewer: What do you find interesting about this one (Porphyry)?

Barry: Black and white spots.

Interviewer: How do you think the spots got there?

Barry: I don't know --------

And with Sarah (9 years, 0 months)

Interviewer: What's interesting about 16 (cement)?

Sarah: It's different shaped and has cracks in it ---- different colours.

Interviewer: What made the different colours?

Sarah: I don't know.

Interviewer: Have you ever seen anything like this before?

Sarah: No.

The prevalence of "I don't know" responses coupled with minimal elaboration which typified younger children's remarks suggested that this age group might not be as suitable for this type of investigation as would older children, the latter having gained more experience through travel, from personal interest and study, or from formal and informal teaching. The older children also demonstrated a greater facility in describing and applying geological concepts, such application including some primative scientific explanations of natural phenomena, explanations which were of interest as far as this study is concerned.

The ability and willingness to express oneself verbally is considered important as far as key informants are concerned (Lofland, 1971), a factor of considerable importance in this investigation.

3. If geological concepts were to be explored in greater depth, the number of concepts to be studied would have to be restricted in order that adequate data be gathered for analysis.

Although the use of rock and fossil collections to stimulate discussion resulted in the generation of useful information about children's understanding of certain geological concepts, this approach was inadequate as far as the generation of significant information from children with respect to any one topic. It, therefore, seemed imperative to involve the children in some activities that would provide greater discussion about fewer topics. My initial reluctance to utilize simulation and analogy exercises as a basis for the study received reinforcement from the data emerging from the initial interviews, fossil formation and its association with an intervention process being a case in point.

A common school-based method for teaching fossil formation to young children is to allow them to make their own 'fossils' by placing a leaf or other material in some wet plaster, allowing it to dry and examining the resulting imprint with a real fossil. This exercise, however, may lend to the result of some children concluding that outside intervention, frequently human, is involved in fossil formation as the following passage illustrates:

Joey: (7 years, 0 months, in conversation about the fossil collection.)

Interviewer: Let's look at another group of objects.

Recognizing artificial material

Joey: Gee, that one looks like a shell. (Referring to plaster of paris cast). Hey, I know how you did that.

Interviewer: How?

Joey: Well, you took soft clay and put the shell into it and then it hardened and you took the shell out.

Interviewer: You think I did that?

Recalling personal 'fossil' making experience

Joey: No, I don't believe so -------- Oh, I've seen these things (fossil fern). You put a leaf in it and you press it in the soft stuff and leave it for a couple of days and then it's good.

Interviewer: Is it a print?

Joey: Yah.

Interviewer: Do you think this one (fossil fern) was formed in the same way as that one (plaster of paris cast)?

Joey: I don't know, maybe ---- hey, look at that one ---- looks like a worm maze ---- a maze worms go in!

Interviewer: Tell me more about 24 (snail fossil).

Joey: Well, I forgot the name ---- like a snail --------

Interviewer: Is it a real snail?

Joey: I don't think so ---- it sort of looks like a rock.

Interviewer: Could a snail turn into a rock like thing?

Time a factor	Joey:	I don't think so ---- left for a 1,000 petrified days?
	Interviewer:	Is this a petrified piece of rock?
	Joey:	I don't think so ---- I mean 100 petrified days ----
	Interviewer:	Do you think it used to be a snail?
	Joey:	Yah, I think that used to be the flesh bone or something.
	Interviewer:	How do you think it got to be like that?
Human intervention	Joey:	I think you did this (snail) and this (fern) and this (clam) the same way as that (plaster of paris).
	Interviewer:	Do you think I did it?
	Joey:	No, maybe someone at the university did it.
	Interviewer:	Were all of these (collection fossils) made by people?
	Joey:	Yah.

4. The hour long interview was too long for the attention span of most children, the thirty minute time period being more appropriate.

After the first half hour of discussion many children began to tire, this being manifested by the utterance of sighs which tended to increase in frequency and intensity over time. Although politeness prevailed, during the last half hour of the interview some children began looking around, others began staring into space and in general the responses became less spontaneous and less elaborate. Consequently, if lengthy discussions were required, consideration needed to be given toward breaking the interview period into smaller segments.

5. Questioning techniques needed to be flexible yet focal, allowing for open-ended responses.

The non-structured interview situation utilizing focal questioning appeared promising in eliciting responses from children while allowing the interviewer to pursue unanticipated or interesting avenues of thought. This flexibility enabled the interviewer to follow-up a range of responses and to recheck observations thus maximizing the possibility of eliciting 'real' (Note 1, p. 61) answers from the children.

Outcomes of Phase I

The 13 interviews introduced a wealth of information which not only focused but also complicated the investigation to some extent. Certain procedural problems were solved and the open-ended questioning produced a variety of responses which provided insight into the understanding which the children displayed of concepts in crystallography, rock and fossil formation and classification and in other geological processes. Although the interviews resulted in a proliferation of potential avenues of study and provided insight into some geological concepts which might reasonably yield to study in depth, they did not provide ready answers as to which specific concepts should be pursued further. It became apparent that the study would be facilitated greatly by the inclusion of 'hands on' activities directly related to specific concepts being investigated. This need to build into the study the use of natural geological materials rather than placing reliance upon the use of analogies or simulation exercises thus became underscored by the preliminary investigation.

The overall outcome of these interviews led to the decision to delimit the study to children of specific age or grade level and investigate a maximum of two or three selected geological concepts. By late 1976, however, the identification of the specific concepts to be investigated and the formulation of activities involving actual geological phenomena/specimens were no closer to resolution.

Phase II

Identifying a Research Setting

Although it is possible, often usual, for a researcher to select concepts for investigation, I remained uncomfortable with this approach because it seemed to be too arbitrary and carried the risk of missing the real problems as perceived by children. The hesitancy on my part to select a priori 'a specific problem' persisted, as did the hope that eventually a real problem would emerge naturally, particularly if the children could become involved in activities focusing on actual geological phenomena/specimens.

My search for geologically oriented activities included consideration of the possibility of observing children in science classrooms in which related topics were being studied. My association with teachers over my years of student teaching supervision had allowed me the opportunity of observing a variety of school science programs, few of which contained units related to geology. In those schools identified as intending to teach some aspect of geology during the year, the focus of attention was upon textbook oriented activities the primary vehicle of instruction being teaching through analogies and simulation exercises involving considerable lecturing and note taking. Although such a setting was that of a natural learning environment, the content and the mode of instruction involved was less than suitable for purposes of my investigation. This situation continued to generate frustration and, eventually, questioning of the feasibility of the entire study, a conclusion apparently reached on previous occasions by others who had considered studies of geological concept development (Karplus, Note 2, p. 61).

Early in 1977 it was learned that a Division II science unit dealing with rocks and minerals recently had been produced by one provincial school board, (see Appendix D). Upon examination, this geologically related science unit appeared to present an ideal vehicle for the pursuit of just the kind of study which I had in mind, involving as it did, an in-depth investigation of the child's understanding of geological concepts as developed in a natural learning environment. The initial step, then, was to locate a class which was about to study the unit and to make arrangements for continuing the research project.

Entry

Gaining Entry

Because participant observation represented a research technique essentially unknown to teachers, it could not be anticipated how they would react to the invitation to participate in such a study. Traditionally, educational research is carried out in a laboratory setting where children's actions can be observed easily and closely or in those instances in which a classroom setting is used, the latter provides a space in which testing, often of the paper and pencil variety is conducted, the researcher entering the classroom only for the duration of the testing process. For most teachers the presence of an outsider in the classroom for extended periods of observation would be a new experience and, because this situation potentially was threatening, careful consideration needed to be given to the entry process.

According to Geer (1964) and Kahn and Mann (1969), entry into a community needs to be initiated both officially and unofficially because this influences how people view the observer. In this case official permission to conduct the study was obtained through the school board's central office for research and evaluation, this permission being subject to the condition that principals and teachers willing to cooperate in the study could be identified. Although the central office was unable to provide the names of such persons, they did suggest that the science consultants employed by the school board might be able to provide assistance, thus paving the way for exploration of some unofficial channels.

In the five years prior to the study working relationships had been established with several science consultants and teachers during contacts made while supervising student teachers, during judging of science fairs and through numerous formal and informal discussions with the science education community. Because this unofficial, but crucial level of support was already in place, and because rapport already had been established with the science consultants, their cooperation and participation in the identification of principals and teachers possibly and potentially willing to participate in the study readily was secured. Ultimately, in fact, a list of possible participants was identified and contact with the schools made in the space of a day.

The first telephone call to a principal (and former science consultant) resulted in an immediate approach to a grade six science teacher in order to ascertain the teacher's possible willingness and interest in participating in the study. This teacher had just begun teaching the unit on minerals and rocks and agreed to an immediate meeting in order that discussion of the study might be carried out in greater detail, a situation which greatly accelerated the entry process.

Establishing Rapport and Defining Parameters for Observation

In addition to explaining the nature and objectives of the study, a primary purpose of the initial meeting was to establish rapport with the teacher and to define the parameters of my role as a participant observer (Schwartz and Schwartz, 1955; Becker and Geer, 1960). Our first conversation was very relaxed and it was soon discovered that we had participated in some of the same educational experiences over the past few years. This fact coupled with the principal's backing of the project contributed to a very positive atmosphere. In this phase of the study we decided that my role would not be concealed although it was anticipated that I would remain primarily a formal observer during class activities. Although observation was to centre primarily on the children's activities, the teacher's activities also were intended to be included in the observational data as part of the description of the total setting, this situation necessitating a certain amount of risk on the part of the teacher. The discussion resulted in permission being obtained to observe one sixth grade class as a source for data gathering, under the conditions mentioned above. Upon reflection, the discussion also revealed several factors which appeared to contribute to the immediate acceptance of the project:

1. The focus of observation was to be the children, not the teacher.

2. There would be minimal disruption of classroom routine. No special scheduling and no special groupings were required, the only disruption anticipated initially being the presence in class of an outsider with a tape recorder.

3. The teacher appeared interested in the nature of the study, particularly that aspect which involved emphasis on observing children in their natural learning environment.

4. My long established working relationship with the school board, science consultants and knowing the principal appeared to lend credibility and acceptance to me as a person and as a researcher.

5. Only one person, myself, would be doing the observation.

6. I was able to begin my observation immediately and in harmony with the current schedule.

Classroom Observation

Over the immediate following three weeks the class of grade six students was observed in their natural science classroom setting, during which time the children worked in groups of four. The initial appearance of an observer seemed to evoke only minor curiosity on the part of the children and, after the teacher gave a brief explanation for my presence in the classroom, activities proceeded as usual. Thus, in the eyes of the children my role was officially established with the children knowing that I was from the University and knowing that I would be present in class for the remainder of the unit because I was interested in learning more about how they, the children, learned about rocks and minerals. Although the presence of the tape recorder initially was a source of curiosity and elicited comments from several students, it seemed to be forgotten as soon as the children became engrossed in the day's activities.

The initial observation plan called for the inclusion of a tape recording of different groups of students during each class period for the duration of the investigation. After several sessions, however, it became evident that the tape recorder could be used much more effectively if concentration was focused upon one or two groups of students. As this procedure became manifest several children who had not been recorded enquired as to when they would 'get their chance', the message transmitted clearly being that they did not want to be 'left out'. Because it seemed important to give everyone a chance to be recorded at least once, if only for purposes of establishing and maintaining rapport, the children who were not intended to form an integral part of the study were 'compensated' by being allowed to spend time after class in recording and playing back their own conversations, a procedure which seemed to satisfy them and helped to maintain good rapport.

In addition to the tape recording of class activities, observation also included the ongoing noting of class activities as a whole and of individual group activities (with activity sheets and class tests) in particular as sources of additional data. Upon completion of the unit, interviews were conducted with four of the students who, according to the teacher, spanned a range of ability levels. The interviews, following the format of those in Phase I, once again were non-structured, focusing primarily upon the ideas that had been presented in class, this focus being facilitated by the use of a collection of rocks and minerals which were used to stimulate discussion. As a culminating activity, a discussion about fossils, utilizing the fossil collection, was included.

Outcomes of Phase II

Observation and evaluation of the Phase II experience, procedures and data resulted in the following observations:

1. _Children working with science materials in the classroom provided a rich source of information for the study of children's understanding of science concepts_.

2. _Intensive observation by this observer must, of necessity, be delimited to one or two groups of children_.

It was necessary to concentrate on one or two groups of children and record their conversations and activities over an extended period of time in order to obtain an intensive observational record.

3. What children did was often as informative as what they said; observation of both language and activity appeared promising.

4. The presence of an outside observer and the use of a tape recorder did not appear to disrupt the normal activity of the children.

5. The number of concepts to be investigated needed to be severely limited.

It was not feasible to conduct a study of all of the geological concepts included in the minerals and rocks unit, however, the particular concepts which would form the focus of the study had not yet been identified by myself.

6. The role of the observer should be revealed and generally informal as typified by a participant-as-observer.

Preparation for Phase III

The classroom teacher provided vital assistance during the evolution of the study by allowing classroom observation, by setting aside time for free and open discussion of the day's activities and by sharing ideas and experiences related to the area under investigation. In addition, the teacher suggested the names of colleagues who might be teaching the same unit and upon inquiry it was learned that one of these teachers recently had taught the unit, the other two intended to do so in the immediate future. Of the latter two, one had been a former pupil of mine at the university and the other had been a cooperating teacher with whom I had worked in the past. Because rapport already had been established with these two teachers, the entry process was telescoped to a telephone call followed by a subsequent meeting. As a result of these meetings, during the course of which the nature of the study was explained, the cooperation of the teachers was secured and their permission was obtained to use their classes as the principle focus of observation for the study. The official sanction of the principals and school board for the total project was then obtained.

Phase III

Entry

Establishing a Role

The third phase of the research project proceeded through additional discussion with the two teachers who had agreed to participate in the study. Because initial entry had been accomplished so readily, attention initially was focused upon the establishment and clarification of my role as an observer. Experience gained from observing in the first classroom suggested that the most appropriate role to adopt for the remainder of the study would be that of participant-as-observer. The teachers and I agreed that my role as a researcher would not be concealed, although we decided that it was not necessary to provide the children with a detailed account of the study. The manner of my introduction to each class was left to the discretion of each teacher which resulted, as it happened, in the children being given similar information namely that I was a visitor from the University who would be joining the class in order to learn more about children's understanding of rocks and minerals. This brief introduction seemed to satisfy the curiosity of most of the children although periodically someone would enquire about my intentions, suggesting that clarification by the children continued to occur as the following sequence with Tim and Sam illustrates:

Tim: (In the middle of an activity) Are you a professor?

Interviewer: Well, I teach there (at the university) but I'm doing this on my own because I'm interested in it.

Tim: Us?

Sam: Because you're interested in how kids react to rocks.

Tim: What reaction we give to different rocks?

Sam: Well, we're studying rocks and you're studying us?

Interviewer: Well, yes. I'm very interested in what you do with the rocks and what you say about them -------- (no further questions).

Establishing Rapport with the Children

Although the introduction by the teachers officially acknowledged my presence in the classroom it still remained for me to establish full rapport with the children, this being accomplished in several ways. Prior to the beginning of the investigation proper I made several visits to each classroom in order to observe the children and to chat with them. This 'ice breaking' technique seemed to be effective, the children gradually beginning to initiate questions and to start discussions with me, a process which carried over into the science classroom as study of minerals and rocks began.

Although the establishment of trusting relationships constitutes a basic condition for the discovery of meaning in a social setting, the cultivation of key informants who are willing to engage in a continuous dialogue about the meaning of what they are doing and saying is of particular importance (Schwartz and Merten, 1971). In the classroom setting the children comprising the group to be observed would become the key informants, thus, special attention was given to getting to know each of the children in these groups, this being accomplished by being with them frequently and engaging them in conversations about their activities both inside and outside of the school.

As familiarity and acceptance increased, these children became very open, feeling free to discuss a broad range of concerns in my presence. Over time it became easier to get caught up in their concerns so in order to avoid going native (Wolcott, 1975) it became necessary to remind myself (not infrequently) of my role and of my objectives so that I could continue to maintain a sense of objectivity and detachment, while still remaining actively involved. Some children came to view me as another teacher coming more and more frequently to ask me for assistance and the temptation to assume the role of teacher increasingly had to be resisted (not always successfully) as the study proceeded.

Establishing Observational Procedures

The experience gained in Phase II of the study led to several decisions regarding the procedures to be implemented during this phase of the observation:

1. One group of children in each classroom was to become the primary focus of observation within the context of the classroom as a whole.

2. Audio-taping would form the basis of classroom observation, this procedure to include the recording of what children said and note-taking to provide observational data on what they did.

3. Student activity sheets and class tests also had presented potential as an observational tool.

4. Additional interviewing would be considered when it seemed appropriate.

Data Collection Techniques

Consideration was given to several alternative techniques for recording children's behaviour in the classroom such as informal observation, rating scales, live observation, and the use of audio-visual recording (Dunkin and Biddle, 1974). Circumstances surrounding the study (nature of the study, time, limited human financial resources and teacher preference) indicated that participant observation reinforced by the use of audio recording presented the most feasible and productive method for collecting data. This combination would allow not only for active participation on the part of the observer but would provide a permanent record of the complex sequence of classroom events which often followed very rapidly upon one another. Delimiting primary observation to one group of children allowed for the production of an acceptable quality of recording despite the noisy environment of the classroom, and the production of a rich source of data was ultimately obtained.

Identifying Student Groups

In order to maintain the natural classroom environment, a decision was made to identify one group from each school for the purpose of in-depth observation. The selection of such groups was influenced by the composition and by the location of the group, the most desirable group being one which included children of varying ability levels and which was located in a section of the room from which general classroom activities could be observed easily. In both schools the selection of an observation site was determined in part by the need to be close to one of the few electrical outlets in the room, the latter, as usual, being located off to one side of the room. Although superficially a mundane factor this concern was nevertheless of vital significance because of the continuous flow of traffic generated by class activities, traffic which must be unimpeded by loose trailing cords.

In one school, four boys forming an heterogeneous group had been assigned to a centrally located table off to one side and located near an electrical outlet. The teacher suggested that this group might be suitable for my purposes and, therefore, it was selected as a primary source for the gathering of observational data. As a group of boys formed the focus of observation at one school, it was decided to observe a group of girls at the second school. This latter group, chosen by the teacher, and also heterogeneous, was in addition, also located near an electrical outlet. As the teacher, however, was uncertain as to the amount and level of verbal output which might be expected to emanate from this group, he suggested that a second tape recorder be placed at a table occupied by four predictably vocal boys, this latter group subsequently becoming a secondary source of observational data. During periods of non-science related activity on the part of the girls it was possible to observe, first hand, this group of boys as well (see Appendix E).

With the direction of the study established, having identified the informants in the study and having narrowed the scope of possible problems to be investigated, it is important to examine several other conceptual variables which provided a framework for the final phase of the study. These are discussed in the following chapter.

Notes on Chapter III

(1) 'Real' in this thesis refers to concepts or situations which represent reality as it actually exists. Real concepts traditionally have been associated with concepts of historical reality while scientific concepts traditionally have been called 'nominal'. Scientific concepts function in a utilitarian fashion, such concepts referring to the arbitrary name which is given to a phenomenon in the interest of scientific investigation. Such phenomena are studied, measured and the reality which exists behind the arbitrary name is thus 'discovered' experimentally, I.Q. being one such example. Real concepts, on the other hand, refers to aspects of reality in human existence, reality as it actually exists in human experience. Generally, the physical sciences emphasize nominal concepts in their vocabulary while the social sciences emphasize the real. Modern social science research and theory includes both real and nominal concepts, a situation reflecting the position of social science between the world of science and the humanities (Bruyn, 1966).

(2) According to Robert Karplus the lack of appropriate activity-oriented geological experiences for young children has discouraged graduate students from doing research in the area "unless they want to spend at least five years doing the study" during which time appropriate activities would have to be developed. He did suggest that one approach to the dilemma might be to observe a professional geologist who is engaged in teaching a group of children, however, the likelihood of finding such a situation was admitted to be exceedingly small.

Karplus went on to note that the development team of the SCIS science program, which he directed, faced similar problems with regard to the lack of appropriate geological activities and they finally decided not to include any geological topics until such time that appropriate activities might be devised. To date the study of geological concepts remains absent from the SCIS program.

(Personal Conversation, October, 1976)

Chapter IV

THE COMMUNITIES, THE SCHOOLS AND THE INTENDED CURRICULUM

Established Communities with Neighbourhood Schools: The Communities and the Schools

The Communities

Phase III of the study was conducted in two urban elementary schools located in different sections of a large metropolitan centre. The city serves as the hub of an important natural resources industry and has experienced steady growth over the past several decades.

Several distinct areas characterize the city. The business and financial district is located in the older central core which is surrounded by concentric zones of residential communities. In addition, industrial areas occur within and peripheral to the city, the oldest and most actively growing of these being located in the northeastern part of the city.

Demographic trends reveal a continual influx into the city of people from other parts of the province as well as from other parts of Canada. The numerous employment opportunities afforded by the buoyant economy have also attracted many immigrants from other countries to the city, adding yet another dimension to an already rich cultural mosaic. This immigrant population has tended to settle first in the older neighbourhoods near the centre of the city, later tending to move into newly developed areas on the fringes of the city as they become more affluent. The residential communities located between these two broad areas are characterized by more stable population patterns.

The continual relocation of family 'breadwinners' associated with the demands of employment has had a marked influence on enrolment and transiency rates at most of the city's schools, those affected most being schools located near the central area and near the outskirts of the city. Schools situated in the buffer zones reflected the stability of well established neighbourhoods and tended to experience stability in enrolments.

The children around whom this study was focussed attended schools which were located in two different areas of the city, one school, Eddington, being located in a residential neighbourhood in the buffer zone and the other, Northland, being situated within the largest industrialized section of the city. Both schools were part of a large public school system including 125 elementary schools in which 29,000 elementary students were enrolled.

Eddington School

Eddington School was located in a stable residential area of the city, an area which began development in the 1950's. The school was built in 1960 following a 'traditional' design, to which an open-area section was added in 1968. The school secretary, a long time resident in the area, described the socioeconomic level of the community as "middle class". Many of the local residents, most of whom came from predominantly European ethnic backgrounds, worked elsewhere in the city at a variety of jobs primarily in the professional and skilled trades areas.

Approximately 350 elementary school children, taught by 15 teachers and assisted by 9 administrative and support staff, attended Eddington School. General academic achievement of the children in the school was described by the principal as being "average" according to school board norms.

Grade Six Curriculum

The grade six program of study at the school followed the general curriculum as prescribed by the provincial Department of Education as modified to a minor extent by the local school board. General subjects included mathematics, language arts, social studies, science, music, art and physical education. The activity oriented science program used in the school consisted of several units developed by science consultants from the local school system and included, among others, selected topics involving the earth sciences.

According to the grade six teacher involved in the study, the earth sciences, as introduced in the *Minerals and Rocks* unit constituted for the children their initial contact with the study of geological concepts as part of a formal science program.

Classroom Organization

Due to the nature of the activities suggested in the *Minerals and Rocks* unit, the teacher decided to use the science classroom for all activities associated with the unit. Since the grade six classroom was situated in the open-area part of the school and the science room was located on the second floor of the old building a considerable distance away, this resulted in a periodic movement of the class to and from the open-area. Once in the science room the teacher allowed the pupils to select their own seats, which resulted in the establishment of groupings for the science class along friendship lines, a situation also regarded by the teacher as heterogeneous. One exception to this arrangement was the group of boys which became a secondary focus for classroom observation. According to the teacher all four boys (Bill, Mike, Reid and Gerry) were "good students" and although long time friends they were, nonetheless, very competitive among themselves. This group selected a table directly in front and to the right of the teacher's desk while the group of girls (Nan, Darla, Penny and Sue) who became the primary focus of observation selected a table near the windows towards the middle of the room. The teacher described the ability level of the girls as one "very bright", one "average" and two "low average". As an observer, I selected a chair at the end of the table among the four girls, thus giving myself a clear view of the entire room (see Appendix E, Figure A).

During the discussions that opened each day's activities the teacher usually stayed near the front of the room, often behind the instructor's long desk within easy reach of the chalkboard, which was used frequently in order to record major points of discussion. While the children were engaged in a particular investigation, the teacher moved freely about the room interacting with the children, asking and answering questions, and periodically interrupting the activities in order to focus attention upon some point of misunderstanding or in order to highlight some significant discovery.

Since the science class was held during the last period of the day, the teacher often gathered science material at noon or during the afternoon recess, and appointed students to assist in distributing and collecting the materials as required, during classtime. This late afternoon class schedule was advantageous for me as an observer because it provided an opportunity for discussion of my observations with the teacher after class as well as an opportunity to speak with individual children about the activities of the day.

Background to the Unit

Prior to the introduction of the Minerals and Rocks unit the class had completed the study of a unit dealing with electricity. Crudely constructed electric motors and generators, evidence of their prior activity, were displayed about the open-area 'room' on the bookcases and tables which served as partitions separating this section of grade six from four other classes and from the multimedia centre. During free time some children were observed completing construction of their projects prior to evaluation by the teacher. A few children continued to work with the electrical materials long after the study of minerals and rocks had begun. At the initiation of the unit, reference books relating to minerals and rocks were made available to the children, and were placed on tables that were readily seen by and of easy access to the pupils.

Northland School

The Northland community, located in one of the oldest neighbourhoods of the city, developed concurrently with the growth of industry in its immediate vicinity. The original school which was built in 1911 was not enlarged until 1954 when the section which is still referred to today as the "new wing" was added. The residents living in the vicinity of Northland School were characterized by the principal as being primarily lower-class working people, many of whom were employed in nearby industries. The principal estimated that 40% of the children attending Northland School came from families supported by social assistance, many of which were single parent families. Accommodation in the area consisted of a mixture of single family dwellings, apartments and low-cost housing developments.

Northland School served as the neighbourhood school for approximately 275 children emanating from varied ethnic backgrounds. Instruction from Grade 1 through 6 was offered, the school being staffed by 15 teachers and professional staff and 4 support staff. Although in recent years the total school enrolment has remained quite constant, the school secretary estimated that perhaps only 25% of the children entering grade one at Northland actually completed grade six at the school. In the area of achievement, the general performance level of the children was described by the principal as being well below the norm for the school system.

Grade Six Curriculum

The general program of study for grade six at Northland School followed the same pattern as that of Eddington School, namely mathematics, science, art, music, social studies, language arts and physical education. Throughout the year the class had been using the same activity-oriented science units recommended and provided by the school board. Likewise, the study of minerals and rocks represented for these children their first exposure to the study of the earth sciences as part of the formal science program.

Classroom Organization

The grade six class was housed in a room which previously had been a science classroom, a factor which continued to affect the environment and the routine of the classroom. The room consisted of two general sections, a large rectangular instructional area containing various arrangements of tables reflecting the flexible use of available space and, off to one side, a smaller rectangular storage area which functioned as a general storage area for science equipment shared by several classes. The school's audio visual equipment was also stored in the same area, so other teachers and children entered the room from time to time in order to collect necessary equipment, adding to the general informality of the setting. Located at the far end of the room was a large commercial mineral display, occasionally referred to by several children during group discussions but which was not utilized formally by the teacher as part of the minerals and rocks study.

The teacher attempted to foster an atmosphere of cooperative learning and sharing among the children with a variable arrangement of the tables in work areas and by encouraging the students to work in groups throughout much of the school day. The actual composition and location of the groups varied from time to time during the lessons depending on the particular subject being studied or on the type of activity being initiated. For the study of minerals and rocks the teacher reorganized the groups which had existed during the study of the previous science unit, resulting in what was described as "heterogeneous" groupings according to sex.

Science Period

The science class was held during the first period in the afternoon allowing the teacher sufficient time to organize the room for the class before the children returned from their lunch break. This timetable also proved to be of optimal convenience for my observational schedule. Being able to arrive well before class began, I had the opportunity to talk with the teacher and to become acquainted with the day's activities. Frequently, several children came into the room before the bell rang and were able to help with the distribution of materials, a task which they pursued with great enthusiasm. On other occasions materials were passed around by the teacher, or by designated students, at appropriate intervals during the class period.

The normal procedure followed was that the children entered the room after lunch, went to their 'home tables', collected their science materials and moved to their assigned tables, the procedure being followed in reverse at the completion of the class period. The group of children (Sam, Tim, Chuck and Roy) which ultimately became the primary focus of my observation during classroom activities sat at a table located on the side of the room next to the windows. From this location the children had ready access to the chalkboard and to the equipment table. As the observer I chose a seat at a table of four boys, between Sam and Tim, a position which also allowed me a view of the entire room (see Appendix E, Figure B).

During science class, no specific area of the room could readily be identified as the 'front'. The teacher worked from a variety of locations within the room, moving periodically from chalkboard to equipment table but, in general, walking among the children while stopping to observe, clarify, question, demonstrate or instruct as the situation demanded.

Teacher Background

The teachers participating in this phase of the study could be described as 'typical' of many elementary school teachers teaching science as part of the general school program, both teachers holding general Bachelor of Education degrees in Elementary Education which included a science methods course, although the methods course did not include any special emphasis relating to the study of geology.

One teacher had taken several biological science courses and one general science survey course which included some exposure to earth science as part of his degree program, but, as he said, "That was a long time ago". Although feeling somewhat inadequately prepared in the area of geology this teacher nonetheless, was quite willing to give the new unit "a try". Most of his 12 years of teaching had been spent in an urban elementary school, some time having been spent in what he described as "inner city school settings".

The other teacher's 10 year teaching career had been divided between teaching in Canada and in Australia although he had taught for several years at the junior high school level most of his experience had been at the elementary school level. During his University years, his only exposure to science had been through the one science methods course in the Faculty of Education that he had elected to take, and, although he relied primarily on his high school science background together with reference books to aid him in teaching the unit, nevertheless, he felt "quite comfortable" with the earth science unit. Throughout presentation of the unit both teachers relied heavily on the accompanying teacher's guide, in addition to related reference books, to provide the necessary information and geological content essential for adequate presentation of the unit.

Hards as Nails:
The Perspective of the Curriculum Developer

Science Unit Associated with the Study

Background to the Unit

The science curriculum unit Minerals and Rocks, designed and written under the auspices of the science consultants of the local School Board, provided the basis for this study (see Appendix D). According to the developer, the unit was designed in response to an expressed need for the inclusion of study of some aspect of the earth sciences, particularly geological concepts, in the Division II (Grades IV, V and VI) science program. The original design of the unit was three times the length of the final version. Selected activities in the areas of geomorphology (stream tables), geological process (sedimentation) and mineralogy (mineral and rock identification) originally had been intended for inclusion, however, time constraints restricted the authors to the inclusion of only the section on mineralogy. Time constraints also resulted in the unit being made available for general use in the school system without extensive piloting of the materials.

The topic of minerals and rocks was selected based on the assumption that children of this age were interested in rocks. The developer gleaned support for this assumption from children's conversations about their rock collections and from the presence of rock collections in many Division II classrooms. Many of the rocks had been collected by children themselves and they appeared interested in learning more about them. Frequently, however, any activity with the rocks proceeded no further, consequently:

> .... the idea behind the unit was to give children a few more skills so they could begin to identify minerals and perhaps extend that into rock identification, too. And, they could enhance their rock collections. (Note 1, p. 97)

Primarily the unit was intended to generate student interest in rocks and minerals. The unit, thus, was:

> .... pretty well totally involved with handling minerals and rocks, making tests on them, trying to identify them through their various properties and to learn some specific things about particular kinds of minerals. (Note 2, p. 97)

Organization of the Unit

The Minerals and Rocks unit was divided into two sections, A and B. In Section A students were asked "to gather data about physical properties of some common minerals and interpret these data in order to identify the minerals (see Appendix D, Teachers Guide, p. 300). In Section B some common rocks were examined in order to determine their mineral composition. According to the developer, the study of minerals was placed before the study of rocks because it was felt that students would be better able to identify rocks if they were familiar with the constituent minerals and had acquired some techniques for identifying them.

Sequencing of Activities

The suggested sequencing of activities was given as follows:

Section A

	Title	Concept
Activity 1	Streaking Minerals	Streak
Activity 2	Hard as Nails	Hardness
Activity 3	Broken Down Crystals	Cleavage
Activity 4	The Prospector's Test for Greenhorns	Classifying and Keying Minerals

Section B

	Title	Concept
Activity 1 (a)	For Rock Hounds	Keying Rocks
(b)	Rock Description	Examining and Identifying Igneous, Sedimentary and Metamorphic Rocks

The developer stated that the sequencing of individual activities was based upon two assumptions, complexity and usefulness. It was assumed that the techniques involved in identifying minerals were set out in such a way that a progression from simple to more complex was achieved as well as a progression from the most useful to the least useful. Accordingly, the streaking activity was placed first because it was assumed to be the simplest and the most useful technique for identifying the common minerals. Although not as simple a technique as streaking the hardness test, nonetheless, was considered to be very useful so the study of this property was placed second in order of presentation. Cleavage was thought to be of limited practical use for identifying minerals because of the element of destruction of the specimen associated with it and thus was placed third in the sequence. The classifying and keying exercises which followed these three test procedures required applying knowledge of several mineral identification techniques in order to ensure completion of the activities and, thus, were placed last.

The study of rocks was limited by design to a few basic activities. Students were asked to identify certain common rocks by use of a mineral identification key. The intention also was that students would be able to distinguish the three basic types of rocks, igneous, sedimentary and metamorphic, and be able to identify some of the more common types, the two activities of Section B being specifically designed with these objectives in mind.

Materials Associated with the Unit

Materials required for completion of the unit included the following:

1. Mineral specimen kits prepared by the Geological Survey of Canada, Department of Energy Mines and Resources (see Appendix D).
2. 13 hand-size rock specimens, including Halite, Slate, Schist, Granite, Limestone, Pumice, Sandstone, Basalt, Obsidian, Quartzite, Conglomerate, Galena and Fluorite.

3. Equipment for testing properties of minerals, including hammers, files, ferrite magnets, streak plates, glass plates, hand magnifiers, copper coins and steel nails.

Mineral Specimens

In general the minerals provided for investigation were not all mono-mineralic specimens. They varied in size and frequently were associated with a second or a third mineral or with different varieties of the same mineral, factors which contributed to an increase in the difficulty level of the activity.

For example, in the sample of Asbestos, thin bands of white asbestiform Serpentine (Chrysotile) were separated, as is typical for this material, by some fairly massive black Serpentine-Lizardite and/or Antigorite, these two latter varieties of Serpentine being of similar hardness. It was almost impossible to determine the hardness of the Chrysotile because scratching of this part of the specimen led simply to a dissaggregation of the fine fibers, the fibers themselves yielding no information relating to scratching. A child unaware of this characteristic of Chrysotile asbestos might well scratch the Chrysotile with a fingernail, observe the separation of the fibers and conclude that the mineral could in fact be scratched by the fingernail. The black Lizardite, which essentially had the same mineralogical composition as the Chrysotile, was scratched by a file and a nail but not by a copper coin. The copper coin could, of course, separate the fibers of Chrysotile.

The Microcline specimen actually consisted of an aggregate of two minerals, Feldspar and Quartz. It was intended that the pink

Microcline Feldspar which made up the bulk of the specimen, should constitute the 'unknown' to be tested. However, in order to be able to determine the hardness of the Feldspar it was important that the student not only should be able to recognize that there were in fact two different minerals present but also to know which one to test.

While, in general, the mineral to be tested made up the bulk of the specimen, this was not always the case. In the Tourmaline specimen, for instance, small black elongated crystals of Tourmaline were randomly spaced throughout the specimen. In this case it was easier and more natural to set about testing the hardness of the bulk host material (Feldspar) rather than the Tourmaline which looked like a contaminant. The small size and brittleness of the Tourmaline crystals also presented a technical difficulty with respect to completion of the hardness test. The Tourmaline crystals had a tendency to break (fracture) quite easily, perhaps misleading the children into thinking that the breaking effect was an indicator that the Tourmaline was scratched by, or softer than, the test instrument (breaking versus scratching is discussed in a later chapter).

Testing Devices

The instruments provided for testing hardness included a steel file, a glass plate, a steel nail, a copper coin and a fingernail, these devices according to the developer being used because they were readily and generally available.

Limitations Imposed by the Testing Devices

The instruments used for testing the hardness of the minerals were very crude measuring devices indeed. A basic rule in measurement is to try to match the magnitude of the units of the measuring device to the magnitude of the object being measured. Accordingly, it well could be anticipated that the testing devices provided would be able to provide a means of distinction between hardness on a very broad basis only. In those instances where two minerals were of very similar hardness, these coarse testing devices are likely (and inherently) of limited use in effecting a distinction.

An additional factor that limited the effectiveness and accuracy of these instruments was the fact that each type of instrument displayed its own range of hardness. Steel files, for instance, might range in hardness from H - 6½ to 8, while copper coins could range in hardness from H - 3½ to 5. Steel nails (H - 5 to 6) could be equal to the hardness of glass (H - 5½ to 6) or slightly softer (Arem, 1973; Lang, 1973; Whitten, 1972).

The Classroom Reality

Sequencing of Activities

In Northland School all activities were studied in the order suggested in the guide. In Eddington School, however, the order of presentation of activities 1 and 2 were reversed, hardness being taught first simply because the streak plates were late in arriving. All other activities were conducted in the order suggested in the unit guide.

Introduction to Materials

Materials and instruments were introduced to the classes in association with each appropriate activity. Streak plates, for example, were introduced during the streaking activity; coins, steel nails and glass plates were introduced during the hardness activity; a hammer was produced for the cleavage activity and magnets first were supplied as part of the classification activity. Once an instrument had been introduced and used, it generally was available for use during subsequent activities. If a given instrument was not available on the student's table, it could be obtained by asking the teacher. For each group of four students the following instruments were available: one streak plate, one or two hand lenses, one or two coins, one or two steel nails, one file, one glass plate and one magnet. The students were expected to share the equipment, distribution and collection of equipment being carried out by designated students.

Time Spent on the Unit

In Northland School the Minerals and Rocks unit was taught over a four week period during May 1977. Class periods lasted between 100-120 minutes, depending on the type of science activity and on other scheduled activities in the school day. Science classes generally were held on Tuesdays and Thursdays although the teacher volunteered to rearrange the class time so that science class was taught on the same day as the science class in Eddington School. This arrangement which was instituted to accommodate me lasted for about a week, disruption of the arrangement being due to the fact that the more flexible schedule in Northland School frequently was altered because of unanticipated school activities. Continuation of the new arrangement on a regular basis became difficult and consequently the class returned to its usual Tuesday/Thursday schedule which was maintained throughout the remainder of the study.

In Eddington School the Minerals and Rocks unit was taught over a six week period during April and May 1977. Science classes were held on Monday/Wednesday/Friday, each class being about 45 minutes duration. As the science class was held during the last period of the day there were few interruptions or schedule changes, although occasionally a class was cancelled for the day. Schedules for the two schools were as follows:

Eddington School

April 20	(W)	Streaking
April 22	(F)	Hardness
April 25	(M)	Hardness
April 27	(W)	Quiz - Hardness
April 29	(F)	Lustre/Cleavage
May 2	(M)	Cleavage
May 4	(W)	Cleavage/Mineral Identification
May 6	(F)	Mineral Identification
May 9	(M)	Mineral Identification
May 10	(T)	Test
May 11	(W)	Rock Identification
May 13	(F)	Field Trip-Museum
May 16	(M)	Rock Identification
May 18	(W)	Rock Identification
May 23	(M)	Rock Identification
May 25	(W)	Discussion - Geological process
May 20	(M)	Rock Descriptions
June 1	(W)	Rock Descriptions
June 3	(F)	Test

Northland School

April 29	(F)	Hardness
May 2	(M)	Hardness
May 4	(W)	Streaking
May 6	(F)	Lustre/Cleavage
May 10	(T)	Cleavage
May 12	(Th)	Hardness Quiz - Classification
May 19	(Th)	Mineral Identification
May 24	(T)	Rock Identification
May 26	(Th)	Rock Identification
May 31	(T)	Rock Descriptions
June 2	(Th)	Reviews, Test

Evaluation Procedures

Evaluation materials were not provided as part of the unit, evaluative procedures being left to the discretion of individual teachers. In Eddington School children were evaluated on the basis of completed activity sheets and teacher-constructed quizzes and tests which were administered periodically at times other than regularly scheduled science periods.

Children in Northland School were evaluated primarily on classwork (activity sheets) and on class participation but no formal tests were planned. Since evaluation materials were not included in the unit, I showed the teacher copies of several quizzes developed by the teacher in Eddington School thinking that these might provide an example of possible test questions. About a week later I discovered that the teacher had decided to use one of the tests as a class activity, as a kind of test intended to initiate discussion among the children. During the following week the same teacher used parts of a second quiz in a similar way, both of these actions being totally unanticipated, but providing me with an opportunity of observing how children in both classrooms responded in a written test to the same set of questions dealing with hardness and other physical properties of minerals (see Appendix K).

A Mineral's Resistance to Scratching: The Perspective of the Earth Scientist

Hardness is only one of several physical properties which give clues to the identity of a mineral and is used rarely as the only criterion in such identification (professionals practicing in the field often employ hardness along with several physical properties such as colour, lustre and cleavage in mineral identification). Because the property, hardness, is expressed in terms of a relative and not an absolute scale it is employed most usefully in those situations which call for approximation. The use of the fingernail and a pocketknife often are together sufficient to ascertain the approximate scratch hardness of a particular specimen. The hardness criterion has limited use in mineral identification outside of field situations because other more sophisticated laboratory techniques are available to identify precisely minerals and their constitutients.

Hardness, although it would appear to constitute a basic characteristic, is difficult to specify accurately in practice because of the relative nature of the scale employed. Its potential as a criterion is only fully realized in the subtle combination of sophisticated knowledge together with extensive practical experience.

Physical Basis of Hardness

The hardness of minerals is related to the nature and arrangement of the atoms included in that mineral. Thus, hardness is related to the nature of the bonding forces between the atoms in the crystal structure. For example, the carbon atoms of graphite are strongly bonded together within layers but the carbon atoms from layer to layer are themselves bonded together weakly (see Figure 1). Thus sheets will tear off graphite when it is rubbed resulting in a soft slippery characteristic.

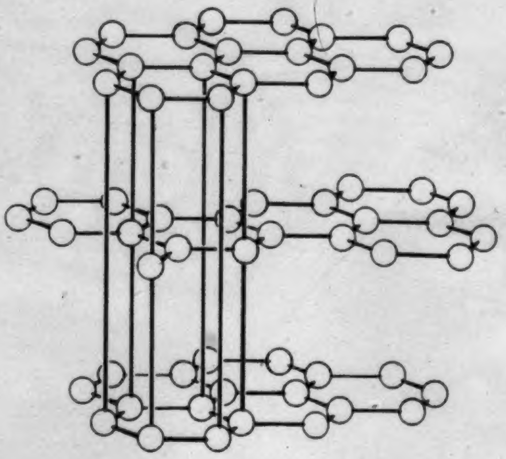


Figure 1. The arrangement of carbon atoms in Graphite

Similarly, Talc shows strong bonding within layers but weak bonding between layers. At the other extreme the carbon atoms which also make up diamond are so firmly bonded that nothing except another diamond is able to scratch it. The carbon atoms of diamond exhibit a compact arrangement, each atom being as close as possible to all other atoms, as illustrated in Figure 2. This compact arrangement of atoms in diamond lends great physical strength to the overall structure and accounts for the unique hardness of the mineral (Gait, 1972). On Mohs scale of hardness graphite exhibits a hardness of 1-2 and diamond a hardness of 10.

In most crystals the arrangement of the atoms are slightly or significantly different in different directions. Because of this the hardness of a mineral may be expected to vary somewhat with direction (Mason, 1968).

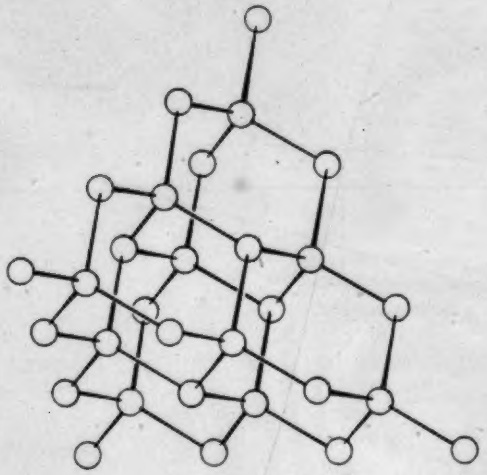


Figure 2. The arrangement of carbon atoms in Diamond

In particular, the mineral Kyanite illustrates an exceptional manifestation of this feature. Crystals of Kyanite usually occur in long flat blades which exhibit a hardness of about 4½ parallel to the blades, while across the blades a hardness of 6½ is manifest. Diamond also exhibits differences in hardness with direction. The carbon atoms, being most densely packed in the octahedral faces, render these faces the hardest in the crystal. The cube planes in Diamond are softest because these faces manifest the least compact arrangement of atoms. This variance in hardness is minor in face of the fact that, in both directions, Diamond is harder than any other known mineral (Gait, 1972).

Definition of Hardness

The hardness of a mineral is generally defined in terms of its resistance to scratching (Mason and Berry, 1968, AGI, 1976). This scratch (scelerometric) hardness differs from indentation hardness (response to a rounded probe applied with a given pressure as employed in engineering practice). Mineral hardness is a qualitative measure which is determined by reference to an empirical scale of standard minerals. The scale in general use today by mineralogists was devised by Mohs in 1822. The fact that the scale is still in use, essentially in unaltered form, is testimony to its functional and qualitative precision.

Mohs Scale of Hardness

Mohs scale of hardness has a range of values from 1 to 10, each value being characterized by a specific mineral:

Mineral	Relative Hardness (H)
Diamond	10
Corundum	9
Topaz	8
Quartz	7
Orthoclase	6
Apatite	5
Fluorite	4
Calcite	3
Gypsum	2
Talc	1

Each of the minerals indicated will scratch minerals lower on the scale and will be scratched by those higher on the scale. It must be stressed, however, that Mohs scale of hardness is based on the relative hardness of minerals rather than on their absolute hardness and that the magnitude of the absolute differences in hardness between the minerals chosen for the scale are not equal. The scale is not linear but approaches an exponential mode in general form (see Figure

3). For example, Fluorite is approximately only one absolute degree harder than Talc and Diamond is about 8½ degrees harder. The relationship between relative hardness on the Mohs scale and the true hardness of these minerals is shown below:

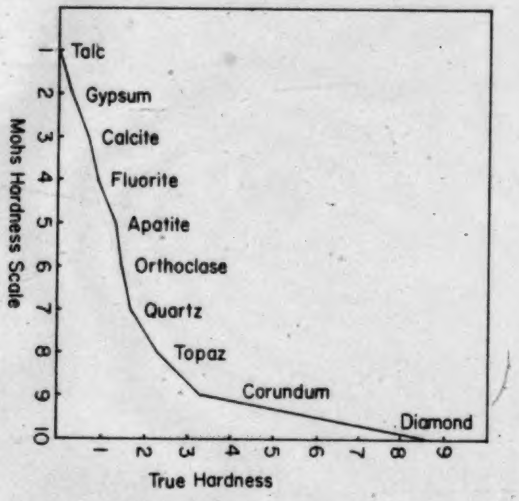


Figure 3. True hardness compared with Mohs hardness scale (Gait, p. 70)

Up to the level of Topaz the hardness interval on Mohs scale are approximately equivalent, the difference in hardness between successive minerals being of sufficient magnitude to allow the scale to be used as a practical basis for determination of the relative hardness of unknown minerals. Its actual use requires the simplest of equipment: a set of specific standard materials of defined hardness. These standards may consist of a set of minerals or at a coarser level of approximation in the field some common objects such as the fingernail, a copper coin or a knife blade, the approximate hardness of which is known, may be employed. Sets of standard minerals commonly contain the first nine minerals in Mohs scale, each reference consisting ideally of a pure fragment of the mineral. In practice, in determining the hardness of the unknown material if the unknown, for example, is scratched by Apatite (H - 5) but not by Fluorite (H - 4) then the hardness of the unknown is said to lie between 4 and 5.

Common Equivalents

In the field many mineralogists find the fingernail (H - 2½) and a pocket knife (H - 5½) constitute adequate tools, minerals of hardness 2 being scratched by the fingernail, and those of hardness 3 and 4 being scratched fairly readily by the knife. Minerals of hardness 5 are scratched by the knife but will themselves scratch glass (Mason and Berry, 1968). Some other lists of common equivalents as proposed by various authors are set out in Table 1. Such equivalents often are recommended by elementary science curricula for use in determining the relative hardness of minerals.

Comparison of Common Equivalents

Since equivalents such as those listed in Table 1 often are recommended by science curricula for use in determining the relative hardness of minerals, it was decided to examine them in order to determine similarities and differences in given hardness. Fingernail hardness was listed as approximately 2½ by three sources; the hardness of a copper coin was given as 3½ in two sources while a third listed it as 5; the hardness of steel pocket knives ranged from 5½ to 7 while that of the steel file varied from 6½ to 8; although the

Table 1

Comparison of Common Equivalents and Mohs Scale of Hardness

Hardness (Mohs)		Common Equivalents			
		Sorrell (Note 3, p. 97)	Mason & Berry (Note 4, p. 97)	Whitten (Note 5, p. 97)	Gait (Note 6, p.97)
Diamond	10				
Corundum	9				
Topaz	8			Hard file	
Quartz	7			Pen knife	
Orthoclase	6	Tool steel		Window glass	Steel file
Apatite	5	Knife-glass	Pocket knife	Teeth, copper coin	Steel knife blade
Fluorite	4				
Calcite	3	Copper coin			Copper coin
Gypsum	2	Fingernail	Fingernail		Fingernail
Talc	1				

hardness of glass was listed as between 5½ to 6, in some cases this value proved to be either less than or more than the listed hardnesses of pocket knives. Similarly, the file hardness, given as less than that of the pocket knife on one scale, was indicated as being harder than the knife on another. It may be noted from all of this that steel and glass manifest some unreliability as hardness indicators as the properties of such materials vary somewhat with composition and manufacture. They suffice, however, as criteria for the provision of approximate indicators of hardness for practical purposes in the hands of experienced users.

Similarly, discrepancies between listed hardnesses of the other reference materials are due to the fact that such materials may display similar variation in composition. Fingernails, copper coins, steel knives, files and glass all display ranges of hardness. Any given piece of steel or glass may vary in hardness by several intervals from another piece of steel or glass. Consequently, steel cannot be assumed always to display the hardness indicated by a particular hardness scale nor will it necessarily be softer than a steel file or any piece of glass. These variations need to be taken into account when designing hardness activities for children.

Hardness Testing

When performing a hardness test certain precautions need to be taken. The surface of the mineral to be scratched initially must be clear and smooth and the testing mineral or object should have a clear sharp edge. After each test a check must be made to determine if, in fact, the mineral was scratched, this verification being necessary because some soft minerals often leave a streak on the harder mineral giving the appearance of a scratch. Any powder produced by a test should be wiped off and the scratch should be subjected to scrutiny, preferably through the use of a hand lens (conventionally X10 magnification) before a definite conclusion is reached. If a true scratch is observed the reference material is harder than the unknown (Gait, 1972). Generally, a systematic approach is recommended, the softest reference mineral being used first with progression towards the harder minerals on the scale. In this way, less damage due to scratching will appear on the test material and a more accurate determination will be possible.

Hardness as Defined in the Minerals and Rocks Unit

In the unit, Minerals and Rocks, mineral hardness was defined as "the ability of a mineral to resist scratching" (see Teachers' Guide, p. 10). A note to the teacher suggested that hardness could be measured by using a common hardness scale: "A rough approximation of hardness can be made as follows:

Hardness Scale

Can be scratched easily by a fingernail
Can be scratched with a copper coin
Can be scratched with a steel nail
Can be scratched with a file
Will scratch glass"
(Teachers' Guide, p. 10)

According to the developer of the unit the usual hardness scale:

Fingernail
Copper coin
Steel nail
File
Glass

was modified so as to allow for more specificity in an attempt to make each test more easily understood by the children. For example, "Can be scratched by a fingernail" was substituted for the "Fingernail" and so on.

Comparison of Hardness Scale Equivalents

A close comparison of the hardness scales as listed in the Minerals and Rocks unit and two other of the hardness scales as listed in Table 1 revealed several significant differences:

Minerals and Rocks Unit: (Note 8, p. 97)	Sorrell:	Whitten:
Hardness Scale (H not given)	Hardness Scale	Hardness Scale
Fingernail	Fingernail (H - 2½)	Fingernail (H - 2½)
Copper coin	Copper Coin (H - 3 to 3½)	Copper Coin (H - 3½)
Steel nail	Steel knife blade (H - 5½ to 6)	Window glass (H - 5½)
File	Window glass (H - 5½ to 6)	
Glass	Metal file (H - 6½)	
		Pen knife (H - 7)
		Hard file (H - 8)

According to Sorrell, the steel knife blade and window glass have approximately the same degree of hardness. Whitten suggested that both the pen knife and the "hard file" are harder than glass. The Minerals and Rocks unit lists the opposite, glass indicated as being harder then either the nail or the file. These apparent discrepancies may exist because of a particular hardness commonly encountered in either steel nails, pen knives, steel files or glass may vary due to intrinsic errors related to sources of steel or glass (batch differences).

A simple hardness test conducted by the investigator using materials prepared specifically for the Minerals and Rocks unit yielded orders of hardness the same as that suggested in the Teachers' Guide. It was observed, however, that although the glass provided was harder than the file, the difference in hardness was not marked. It should be noted, nonetheless, that although the hardness of steel or glass generally may vary to the extent that a particular piece of glass might be harder than a particular steel file, the difference in hardness between the two substances appears small, particularly to the untrained observer.

Given that the glass which initially accompanied the Minerals and Rocks unit was harder than the files, the possibility still existed for teachers to supply additional files and pieces of glass from other sources, particularly since they were not cautioned against doing so. The Teachers' Guide did not discuss possible variations in hardness of steel and glass so, unless individual teachers were aware of this possibility, they easily might substitute or add files, glass and steel nails of varying undertermined degrees of hardness. Such substitutions or additions might then complicate a particular classification activity.

Hardness Testing

The following information relating to the manifestation of a scratch was provided for teachers in the Teachers' Guide:

> Students will need help in deciding whether a mark made by a mineral or copper coin or glass is a scratch. Gypsum for example may leave a white powder or streak when it is rubbed on glass, however, the powder can be easily rubbed off the glass. This shows that the mark was not a scratch and that glass is harder than gypsum. The mark made by quartz on glass cannot be rubbed off. It is a scratch. Use this example to introduce the students to the technique of determining hardness. (Teachers' Guide, p. 10)

No mention was made regarding the condition of the material to be scratched, or the condition of the mineral to be tested or which part of the reference test mineral was to be used to scratch the 'unknown' — a very important consideration.

Hardness Range

For purposes of analysis in this study, the concept of 'hardness range' was developed. For a given set of minerals the hardness range was taken as the difference between the softest and the hardest minerals. For example, the hardness range would be 5 for a group containing the following minerals:

Stibnite H - 2
Calcite H - 3
Fluorite H - 4
Chromite H - 5½
Quartz H - 7

7 - 2 = 5

Because the intervals between successive hardness values are not equal it should be remembered that this again is only a relative range, not an absolute range. Nonetheless, hardness range as a concept is useful in demonstrating why hardness is a property difficult to determine with accuracy (Note 9, p.97).

It must be noted that the hardness range for some sets of minerals may vary. Consider the following group of minerals:

Graphite	H - 1 to 2
Muscovite	H - 2½
Siderite	H - 3½ to 4
Apatite	H - 5
Quartz	H - 7

Since the relative hardness of Graphite is known to vary from 1 to 2, the hardness range for this set of minerals might be 5 or 6, depending on the hardness of the particular Graphite specimen that is being tested, this relative hardness variation of a particular mineral being due to slight variations in the crystal structure or in the composition of the specimen. Thus, in addition to hardness range it was sometimes useful to calculate the 'minimum hardness range' likely to be encountered because the latter represented the maximum difficulty level which a child might confront when testing and ordering a given set of minerals.

The Teachers' Guide suggested that seven mineral groups be used in the hardness activity. Of these groups, five exhibited a minimum hardness range of 5, one group exhibited a minimum hardness range of 5½ and one 6 as shown in Table 2. These ranges are considerably smaller than the minimum hardness range of 9 for Mohs scale and it was anticipated that mineral groups which exhibited smaller

Table 2

Hardness, Hardness Intervals and Hardness Range for Mineral Groups Suggested in the Teacher's Guide

Mineral Group	Mineral Number	Mineral Name	Hardness (Mohs)	Hardness Intervals (Minimum)	Hardness Range (Minimum)
A	3	Molybdenite	1-1½		5½
				1	
	6	Galena	2½		
				1	
	7	Chalcopyrite	3½-4		
				1½	
	12	Chromite	5½		
				1½	
	22	Quartz	7		
B	4	Graphite	1-2		5
				½	
	11	Manganese Ore	2½		
				1	
	8	Pyrrhotite	3½-4½		
				1½	
	9	Pyrite	6-6½		
				½	
	23	Quartz	7		
C	5	Stibnite	2		5
				½	
	17	Muscovite	2½		
				½	
	19	Barite	3-3½		
				1½	
	31	Apatite	5		
				2	
	36	Tourmaline	7-7½		
D	15	Talc	1		6
				2	
	18	Calcite	3		
				½	
	25	Siderite	3½-4		
				1	
	13	Ilmenite	5-6		
				1	
	22	Quartz	7		
E	16	Gypsum	2		5
				1½	
	20	Anhydrite	3½		
				½	
	30	Fluorite	4		
				1½	
	14	Magnetite	5½-6½		
				½	
	23	Quartz	7		
F	3	Molybdenite	1-1½		5
				1	
	24	Phlogopite	2½		
				1	
	34	Sphalerite	3½-4		
				2	
	21	Albite	6		
				½	
	28	Garnet	6½-7		
G	4	Graphite	1-2		5
				½	
	29	Asbestos	2½-4		
				0	
	7	Chalcopyrite	3½-4		
				2	
	27	Microcline	6		
				1	
	36	Tourmaline	7-7½		

hardness ranges might be more difficult to order than those which exhibited a larger hardness range.

Hardness Intervals

The concept of 'hardness intervals' was developed to illustrate further the difficulty level associated with testing and ordering minerals according to hardness. For the purposes of this study a minimum hardness interval was defined as the least difference in hardness between any two adjacent minerals in a given mineral group. Again it must be remembered that the minimum hardness interval represented a relative difference, not an absolute difference. It was used here to demonstrate how similar the minerals recommended for use in the activity were in hardness. It was anticipated that the ordering of minerals closest in hardness on the Mohs scale (smallest interval) might be more difficult than those which were farther apart in hardness (larger intervals).

Table 2 shows that hardness intervals with the mineral groups suggested for use in the unit ranged from 0 (Group G) to 2 (Groups C, D, and E). Of a total of 28 possible minimum hardness intervals, a minimum interval of 2 occurred only four times. A minimum interval of 1½ occurred six times, a minimum interval of 1 occurred eight times and a minimum interval of ½ occurred nine times. In one case, the minimum interval was 0, that is, the two minerals suggested for comparison might exhibit exactly the same hardness. With a minimum interval of 0, differentiation between the hardnesses of the minerals, particularly with the crude implements available, might well be anticipated to be virtually impossible. The intervals, ½ and 1, which occurred 17 of a possible 28 times also required that the children make fine distinctions between minerals very similar in hardness using relatively coarse measuring devices. A minimum interval of ½ occurred in all but group A, while in groups D, F, and G it occurred once and it occurred twice in groups B, C, and E.

The manner in which children experienced and applied the concepts discussed here is examined in the next chapter. An analysis of their behaviour is exhibited during related activities reveals the children's perspective of mineral hardness and indicates how they applied their understanding to the tasks at hand.

Notes on Chapter IV

(1) From a taped conversation with a developer of the unit in which the background to the unit was described.

(2) Ibid.

(3) Sorrell, C. Minerals of the world. New York: Golden Press, 1973.

(4) Mason, B., & Berry, L. G. Elements of mineralogy. San Francisco: W. H. Freeman and Co., 1968.

(5) Whitten, D. G. A. A dictionary of geology. Great Britain: Hazell Watson and Viney Ltd., 1972.

(6) Gait, R. I. Exploring minerals and crystals. New York: McGraw Hill, 1972.

(7) Also intuitively used by a child.

(8) According to the developer of the unit this particular hardness scale was taken from a reference book, the source not certain.

(9) In this instance 'hardness range' is not being used in what might be considered the strict sense of the term. For purposes of emphasis, some liberty is taken in extending the meaning in order to illustrate the hardness spread between the extremes in a group of minerals whereas, normally, one might speak of hardness range in relation to a single mineral.

Chapter V

THE EXPERIENCED CURRICULUM

"What you Could do is Try to Scratch Them with a Variety of Things": The Curriculum as Interpreted During Classroom Activities

Introduction to the Property

The physical property of hardness was introduced to both classes by the teachers. In one classroom the teacher began by initiating a discussion about the different characteristics of rocks, the children contributing suggestions regarding texture, lustre and colour. As no child made mention of hardness as a possible criterion the teacher introduced the idea with a reference to breaking:

Associating hardness with breaking	Teacher:	There is another characteristic of rocks and minerals that you haven't mentioned that I'd like you to investigate today and this is the hardness of rocks. Now perhaps you thought about this, but some rocks are soft and easy to break and others are not quite as soft; they're hard. Can anyone suggest a way (of testing for hardness)?

The children centered on the breaking idea and expanded on it by suggesting methods of testing hardness related to breaking:

Picking up the breaking cue and expanding on it.	Jim:	Break them.
	Sally:	Bang them on the table.
	Cathy:	Drop them on the floor.

The idea of scratching as a test for hardness did not appear spontaneously although one student who had been reading ahead on the activity sheet suggested scraping the mineral with a nail. This led to a teacher-directed discussion of how to use the scratching criterion as had been suggested on the activity sheet.

In the other classroom, hardness was the second physical property studied after the class had completed the streaking activity. During the introductory discussion at the beginning of the unit on minerals and rocks, one student briefly mentioned hardness as one of the physical properties of minerals:

Teacher: Anything else (other physical properties) that come to mind?

Sam: Hardness ---- like some you can't break. Like you have to use so much acid or something.

When the class formally started a study of hardness (Activity 2) the teacher moved the children directly to the activity sheets:

Teacher: We're going to look at the first two questions on on the next unit. If we're working with streaking in Investigation One, what does it look like we're testing in Investigation Two?

Sandie: The fingernail and the penny.

Teacher: We're testing the fingernail and the penny. Can you be more general?

Jim: We're going to test the hardness of rocks.

Teacher: He says we're going to test hardness. Terry?

Terry: The hardness.

Teacher: You agree ---- just at what you've glanced at. (Teacher passes out pennies and nails.) To do these activities you do need a penny and a fingernail and a nail. (Students begin working on Questions 1 and 2.) (Appendix F, T4/2-3)

Neither in the introductory nor in the developmental activities did any of the children in either classroom end up by actually defining hardness as 'the ability of a mineral to resist scratching'. Although this was not a specific instructional objective of the Unit, the developer of the Unit anticipated that children would, in fact, come to this understanding through involvement in the activities. The teachers did not give this definition to the classes or discuss it and no classroom encounters were recorded which dealt with any common-sense understandings about hardness that the children might have acquired through everyday experience. Although the idea of breaking was mentioned briefly, attention was quickly diverted to the activity sheets and the children began using the scratching criterion strictly within the context of the defined activity.

Initiation of Work with the Materials

After reading through the first question on the activity sheet,

> Question 1: Try to scratch a penny with the point of a steel nail. Then try to scratch the steel nail by rubbing a penny across it.
>
> (a) What did you observe?
>
> (b) Which material is harder?

the children began to work at once with the materials provided. The question "Which is harder?" provoked immediate discussion among the children in one classroom:

	Penny:	(Reading) "Which material is harder?" I think the penny is.
Demonstrating logical thinking; using scratching criterion	Darla:	But Penny, why does this (nail) scratch that (penny) instead of this (penny) scratching that (nail)?
Associating hardness with bending, not scratching	Penny:	Which is harder, not which one scratches! You could bend this (nail). It would be pretty hard to bend a penny.

Diverted to bending idea again	Darla:	Yah. But if the penny were round and skinny you could! (Appendix F, T6/6)

A similar discussion was observed in the other classroom:

	Tim:	(Reading Question 1(b)) "Which is harder?"
	Sam:	The nail.
	Chuck:	The penny! Nail????? I can't bend a penny, but I can bend a nail.
Associating hardness with bending	Tim:	You can't bend it. If you could stretch a penny, I bet you could bend it.
	Chuck:	Okay. Try to bend the nail. (Tim tries to bend the nail.)
	Roy:	Look, he's trying as hard as he can.
	Chuck:	Hey, look!
	Tim:	Look, Chuck! (Hitting penny with nail.) See, you can see a hole by the maple leaf.
	Chuck:	Oh, it did.
Associating hardness with breaking	Sam:	Let's see the hole. (Sam examines the hole. They all try to dent the penny and the nail by pounding both of them.) (Appendix F, T4/3)

After completion of Question 1, the children moved on to Question 2 which read:

> Question 2: Scratch one of your fingernails by rubbing the edges of a penny firmly across it. Then try to scratch the penny with your fingernail.
>
> (a) What does this indicate about the hardness of the penny compared to your fingernail?

Most children worked through this question quickly and indicated the fingernail as the softer object. Only passing reference was made to this part of the activity as illustrated by the following discussion which was observed in one classroom.

Applying scratching criterion as intended	Reid:	(Examining his fingernails) Hey, my fingernail is gone! (Reads Question 2) "Scratch one of your fingernails by rubbing a penny firmly across it." (Each child in the group does his own testing.)
Outcome uncertain	Gerry:	(Still not certain what happened between the penny and the nail) How do you do this? (No one responds to this question)
	Bill:	None of them get scratched.
	Reid:	Then try to scratch the penny with your fingernail. (Nothing happens.)
Demonstrating logical thinking	Bill:	The penny is harder.
	Mike:	The penny is harder.
	Bill:	(Reading) "What does this indicate about the hardness of the penny?"
	Bill:	It's (penny) harder. (All agree and the group moves on to the next question.) (Appendix F, T6/9-10)

Although the children applied the scratching criterion in practice, in their comments during discussion many of them continued to associate hardness with bending or breaking. They appeared to use the scratching criterion because the activity called for it and because the material allowed for it. When the teachers decided to move on to the study of the hardness scale, some children still were not convinced that the nail was harder than the penny. It also should be noted that the title of the activity "Hard as Nails" suggests an association of hardness with a meaning other than resistance to scratching and although catchy, it may have been misleading to some children.

Using the Hardness Scale

Both classes were introduced to the hardness scale through the reading of question 3 of the activity:

> Question 3: A simple hardness scale is given below. Use it to place, in order of increasing hardness, the five minerals provided your group. Work on your own then compare your ranking with others in your group. Test again if you have any disagreements.

For purposes of this exercise each group of children was given a plastic bag containing five minerals. The children tested the minerals by applying the hardness tests suggested in the hardness table:

Can be scratched easily with a fingernail	Softer
Can be scratched by a copper coin	
Can be scratched by a steel nail	to
Can be scratched by a file	
Will scratch glass	Harder

The initial reaction to the manner in which the table was set out suggested that the children found it confusing. Some of the typical remarks heard around the classroom were:

Gerry: I don't get this. What is "softer to harder"?
Penny: Nan, how do you do this chart?
Reid: How do we do this?

However, further clarification from the teachers seemed to enable most of the children to use the table, and thus it appeared that they possessed the thinking skills required to order minerals according to a given scale. In other words, they seemed able to reason logically. For instance, if a mineral were scratched by a copper coin but not by the fingernail, the children concluded that the mineral was harder than the fingernail but softer than the coin.

The language used in the hardness table, however, presented a problem for some children. At first these children seemed to overlook the difference between "Can be scratched" and "Will scratch" even though it was extremely important to the success of the exercise to understand this distinction between the object doing the scratching and the object being scratched, or the 'scratcher' and the 'scratchee'. It was not until study of the unit was well under way that one teacher realized the children might be experiencing a difficulty in making this distinction. After talking about the language involved and working through several verbal and written examples containing the specific words, "Can be scratched" and "Will scratch", children became able to apply the statements correctly and by the end of the unit most children were able to deal with the scale quite easily.

Further evidence which suggested that the children were able to manipulate the logical thinking skills involved was obtained by examining results of class quizzes, identical versions of which were used in both schools (see Appendix K). In these quizzes, children first were asked to list in order of increasing hardness the 'tests' used in class for the determination of mineral hardness (fingernail, copper coin, nail, file and glass). After recording this information children then were asked to determine the order of hardness of a set of unknown minerals which was provided in the form of written statements. The following was one such task:

Write the following mineral sample numbers in order of hardness from softest to hardest.

#1. Scratches a copper coin but a steel nail scratches it.

#2. Scratches a steel nail but not a steel file.

#3. Scratches glass.

#4. Can be scratched with a fingernail.

#5. Scratches fingernail but not a copper coin.

#6. Can be scratched by glass but not by a steel file.

(Correct order: 4, 5, 1, 2, 6, 3)

In general the children at Eddington School experienced little difficulty completing this sort of task with most of them coming up with the 'correct' order of hardness. Although children at Northland School initially experienced difficulty with such tasks, following a teacher-initiated discussion regarding the language being used, these children, too, were able to complete the activity quite accurately. It should be noted here that this sort of task is essentially a logical-thinking task, the use of minerals actually being quite superfluous to it, in essence a means to an end. Given a hardness scale and understanding how it 'works', tasks of this nature can be completed 'correctly' without any knowledge of mineralogy. The danger lies in assuming that the ability to correctly order a fictitious set of minerals also reflects an understanding of certain scientific concepts. In fact, the task of ordering an actual set of minerals is quite another thing, requiring, in addition to logical-thinking skills, knowledge and technical skills of a sophisticated and scientific nature.

In their encounter with minerals the children were observed to use several procedures for testing hardness. Some children worked systematically through the tests beginning with the fingernail test, others selected tests at random, while some did not even try every test on each mineral. Although the teachers suggested that they apply the tests in a given order, not all children did so although, over a time, most children became more systematic in their work.

Sometimes the children had difficulty deciding whether or not a mineral had been scratched. For example:

Reid:	(Talking to himself) Okay. Now what do we do? (Studying the hardness scale) "Can be scratched with a fingernail." (Scratching the mineral with his fingernail) Yup.
Mike:	Your's can? Let's see.
Reid:	See, right across here.
Bill:	(Scratching his mineral with his fingernail) I can't tell with mine.

The teachers reminded the children to check for the presence of an actual scratch, one teacher telling the children that they could differentiate between a scratch or a mark by trying to rub it off. The other teacher referred somewhat more obliquely to this information in his discussion. Throughout the study, however, few children consistently rubbed the mineral after each attempt at scratching and this failure to use the experimental technique correctly could have been a significant contributing factor to the children making incorrect inferences regarding the hardness of a given mineral.

Recording on the Hardness Scale Table

After performing each hardness test upon a mineral, the children recorded the results directly upon a table, Tim's table being a typical illustration of the manner in which many of the children completed their tables:

Table 3

Tim's Hardness Table

Hardness Scale	Mineral Sample
Can be scratched easily with a fingernail	4
Can be scratched by a copper coin	29 4
Can be scratched by a steel nail	29, 36, 4
Can be scratched by a file	29, 27
Will scratch glass	29, 36, 27, 4

When the children began to record a mineral sample number in more than one space, the teachers reminded them that they should record the number in only one place, repeating the suggestion that testing should begin with the fingernail, proceed in order to each subsequent test, and should terminate after registration of the first scratch test that worked. The mineral number was then to be recorded in the space adjacent to a description of the task and, in this way, the order of mineral hardness would emerge. Unfortunately, these directions presented a source of great confusion to many children. At first they could not understand why a mineral number should be recorded in only one blank, especially since more than one test produced a scratch, so some children ended up by erasing a particular mineral number from all but one blank while others left their recordings as they were originally and continued to record in more than one blank. Tim's continual frustration was typical of many children, as this discourse illustrates:

Recording 'incorrectly'	Sam:	(Noticing that Tim is recording mineral numbers in more than one blank) You can only have one number on the line.
Not understanding hardness table	Tim:	Why? (Annoyed) I don't get this. (The teacher joins the group and noticing Tim's problem, attempts to clarify the procedure for him.)
	Teacher:	Okay. Number 4 will only go in one place. How hard is it? Okay, once you've determined how hard it is, that's where you put it (the mineral number).
Unable to use hardness table as intended Frustration persisting	Tim:	(Continues to work for the next several minutes but still experiences difficulties. He changes minerals often, looking for one that will give a definite result. By the end of the class period, he is still confused.) I don't get this! (Gives away mineral 13 and takes 25; begins scratching the glass again, working quietly for several minutes.) Do you put the one that could be scratched with your fingernail the easiest? (Reads chart.) This is a dumb chart! (Appendix F, T5/13)

When professional geologists were presented with similar groups of minerals with the same test instruments and with the hardness scale from the activity sheet, they also recorded the minerals in more than one blank. In discussing their actions, the professional geologists indicated that they did not understand that the directions specified that a mineral number should be recorded only once. Neither did they spontaneously order the minerals and their completed tables, interestingly, bore a close resemblance to those produced by the children. This would seem to suggest that the difficulties experienced by both the children and geologists in using the table was due in part to the lack of clear directions or that children and professional geologists both have similar approaches to problems presented in a specific manner. The first inference was substantiated during the completion of a terminal exercise at the completion of the unit when children were given a simplified hardness scale which listed only the test implements:

fingernail	Softest
copper coin	
piece of steel	to
file	Hardest

Using this scale the children were asked to order a given set of minerals and record their ordering in a set of boxes provided for that purpose:

☐ ☐ ☐ ☐ ☐

Softest --→ Hardest

Observation of children's work revealed that they were able to operate easily and systematically with this system.

A Problem Emerges

Observations during the first weeks of presentation of the Minerals and Rocks unit suggested that children were experiencing several difficulties which included differentiation between the hardness of a penny and the hardness of a nail, the association of hardness with breaking and the manipulation of the hardness scale. I became, as an observer, overwhelmed by a "confusing welter of experience" (Whyte, 1955, p. 357) and it became impossible, at this time, to identify one specific problem as being of overriding importance, 'too many problems' having emerged.

I suspected that the children's difficulty with mineral ordering might be related to their inability to think logically and systematically and, for several weeks, I considered this to be an area in need of more study. Accordingly, I worked on developing an alternative hardness scale that would be clear, simple for the children to use, and easy to analyze. I also considered the possibility that the nature of the minerals used might contribute towards the difficulties experienced by the children, another possible factor of significance being the poor techniques pursued by the children. A wide variety of factors possibly affecting the way in which the children operated seemed to emerge but it was unclear which of these, if any, were of significantly greater importance than the others. These ambiguities, coupled with a steady progress through the unit by the classes, made identification of 'the problem' inherent in the exercise a pressing matter, to say the least.

Further observation over the next few weeks revealed that certain events recurred quite regularly, particular behavioural patterns surfacing on a repeating basis regardless of the activity. One recurrent theme was the way in which children talked about hardness, in that they continually associated hardness with breaking. Another theme concerned the methods used by the children in testing for hardness, for although they applied the scratching criterion as directed, they often spoke about how "easy" it was to scratch an object and remarked about the size of the chips that broke off a mineral. By this time, however, the actual use of the hardness scale seemed to present less of a problem for the children, perhaps because only specific restricted tests employing the scale were used in the later activities. When an individual and specific test was called for, the children seemed able to cope with the issue quite readily and it was not until the classes were into the latter part of the unit that I decided to investigate in greater depth two aspects of the hardness activity which seemed to manifest recurrent problematic aspects. These two areas, encompassed by the children's beliefs about the meaning of hardness and by their methods of testing for hardness, seemed significant as they appeared to be fundamental to a full understanding of the methods and procedures employed by the children in a task situation. More specifically, I decided to focus on the questions (1) What are children's understanding about the physical property hardness?, and (2) How do children test for hardness? The observations and interpretations that follow relate specifically to these research questions.

Identifying Hardnesses

A number of children found that a particular hardness test 'worked' for more than one mineral at a given set. Some of their observations are recorded in Table 4 showing that within mineral group B, for example, both specimens number 11 (Manganese) and 4 (Graphite) could be scratched easily by a fingernail while numbers 23 (Quartz) and 9 (Pyrite) both scratched glass.

Table 4

Children's Observations of Mineral Hardness

Hardness Test	Mineral Number	
	Group B	Group E
Can be scratched easily with a fingernail	11, 4	
Can be scratched by a copper coin	8	16
Can be scratched by a steel nail		20, 30
Can be scratched by a file		14
Will scratch glass	23, 9	23

The observations indicated that these children found that a given hardness test did not always differentiate between the hardness of two minerals. It was noted also that professional geologists working with some of the minerals made similar observations, one such set of observations being illustrated in Table 5.

Table 5

Geologist's Observations of Mineral Hardness

Hardness Test	Mineral Number
Can be scratched with a fingernail	29
Can be scratched by a copper coin	29?
Can be scratched by a steel nail	29, 7?
Can be scratched by a file	29, 7, 5 (silver only)
Will scratch glass	29 (black), 7, 5 (white only), 27, 36

Such observations led me to examine more closely the mineral groups used in these activities. The hardness range and hardness intervals for each mineral were examined, and a comparison was made between the results obtained by the children and by the geologists.

It was anticipated that small minimum hardness intervals might present difficulties for the children in their attempts to differentiate between the hardness of different minerals. This problem is especially likely to be anticipated if one considers the (absolute) hardness of the minerals involved (see Figure 3, p. 85), coupled with the likely variation in hardness of the test instruments. Analysis of the results obtained by children, several of which are shown in Table 6, did reveal difficulties which might be attributable to small hardness intervals.

In mineral groups B and E, for example, some children placed three pairs of minerals at the same hardness level — 11 (Manganese) and 4 (Graphite); 23 (Fluorite) and 9 (Pyrite); and 20 (Anhydrite) and 30 (Fluorite). All of these pairs displayed minimum hardness intervals of ½. In group G, three typical examples of results show that even when children did place a mineral at only one hardness level, often there was little consistency in their final orders of hardness, with none of the orders matching the 'correct' order of hardness. Closer scrutiny of these results show that the children's orders of hardness varied from the 'correct' order in that minerals adjacent to each other, Graphite (4) and Asbestos (29), for instance, often were reversed from the intended order. The placement of Chalcopyrite (7) and Asbestos (29), and Microcline (27) and Tourmaline (36) displayed a similar pattern. Once again it is noted that minimum hardness

Table 6

Children's Hardness Test Results for Mineral Groups B, E & G Using the Class Hardness Scale

Class Hardness Scale	Children's Results				
	Group B	Group E	Group G		
fingernail	11, 4		29	29	4
copper coin	8	16	4	4	7
nail		20, 30	7	7	29
file		14	29	27	36
glass	23, 9	23		36	27

Note. 4 - Graphite (H=1-2)

16 - Gypsum (H=2)

11 - Manganese Ore (H=2½)

29 - Asbestos (H=2½-4)

20 - Anhydrite (H=3½)

8 - Pyrrhotite (H=3½-4½)

7 - Chalcopyrite (H=3½-4)

30 - Fluorite (H=4)

14 - Magnetite (H=5½-6½)

27 - Microcline (H=6)

9 - Pyrite (H=6-6½)

23 - Quartz (H=7)

36 - Tourmaline (H=7-7½)

intervals for these three pairs of minerals are ½, 0 and 1 respectively. Although this factor alone might make differentiation between hardness difficult, when coupled with the use of imprecise implements as noted, problems multiply.

Two of three professional geologists working with mineral group G also observed several minerals to be similar in hardness. Their results are shown in Table 7 (Note: mineral group X was identical to Group G with the exception of Stibnite (H-2) which was substituted for Graphite (H-1 to 2). Like the children the geologists placed several minerals, 27 (Microcline) and 36 Tourmaline); and 29 (Asbestos), 27 (Microcline) and 36 (Tourmaline) in the same hardness categories, these minerals being selected for discussion because the 'correct' mineral part of the specimen was tested. Two of the minerals, 27 (Microcline) and 36 (Tourmaline) displayed a minimum hardness interval of 1 while the others, 29 (Asbestos) and 27 (Microcline), and 29 (Asbestos) and 36 (Tourmaline) exhibited minimum hardness intervals of 2 and 3 respectively. Nonetheless, the geologists were unable to distinguish between them on the basis of the hardness criterion solely by the use of the implements provided. They were, however, able to differentiate between minerals 29 (Asbestos) and 7 (Chalcopyrite) which theoretically manifest a minimum hardness interval of 0. In this instance it is possible that these particular mineral specimens did not display the true minimum hardness interval one might expect from 'standard specimens', thus a difference was noted.

In the foregoing analysis one parameter, minimum hardness intervals, which might affect the difficulty level encountered in

Table 7

Geologists' Hardness Test Results for Mineral Groups G and X Using the Class Hardness Scale

Class Hardness Scale	Geologists' Results	
	Group G	Group X
fingernail	4, 29 (white)	29?
copper coin	29 (black), 36 (black)	29?
nail	7	7?
file		5 (silver)
glass	36 (pink), 27 (pink)	29 (black), 5 (white), 24, 27, 36

Note. 4 - Graphite (H=1-2)

24 - Stibnite (H=2)

29 - Asbestos (H=2½-4)

7 - Chalcopyrite (H=3½-4)

27 - Microcline (H=6)

36 - Tourmaline (H=7-7½)

rank ordering minerals according to hardness, was discussed. Although only relative differences in hardness were considered in the analysis, these differences were useful in demonstrating that hardness intervals need to be considered when developing mineral ordering activities for children.

Other Factors Affecting Hardness Differentiation

Identifying and Testing the Principal Mineral

Additional factors which might have influenced the children's conclusions regarding mineral hardness were the nature of the minerals and the type of implements used in the measurement process.

Few of the minerals used in this unit were pure specimens and in many instances the mineral to be tested did not make up the bulk of the material. For example, mineral sample 36 (Tourmaline) consisted primarily of pink Feldspar with a few small black Tourmaline crystals embedded in it. In this instance the children had to recognize that more than one kind of mineral was present in the specimen; then they had to identify the principal mineral to be tested. Many children failed to do this and those who did recognize that multiple minerals were present were not always able to identify the principal mineral. Generally, the children guessed or asked for assistance although sometimes the teacher, too, was not certain which was the principal mineral. In mineral sample 29 (Asbestos) there was not only more than one mineral present, but more than one variety of a particular mineral (Serpentine). The specimen consisted of asbestiform Serpentine (white) which formed a series of alternating bands with fairly massive Serpentine (black). Although both varieties were of similar hardness, it was impossible to test the asbestiform variety because of its fibrous occurrence, the individual fibers being extremely fine and often separable on the basis of finger pressure alone. Many children scratched the asbestiform mineral with their fingernails and when the fibers separated, they inferred that the mineral was scratched by a fingernail although actually they proved nothing. The black Serpentine, on the other hand, was scratched in the true sense by a nail, but not by a copper coin.

One child, Sam, noticed that there was more than one kind of substance in the Asbestos specimen, but became confused over which part to test. After testing both and finding that he could scratch the white part but not the black part with his fingernail, he then became unsure as to which observation should be recorded in the hardness table:

Recognizing different substances present

Sam: (Noticing the white fibers, but not certain which part of the specimen to test. He begins with his fingernail.) Teacher, I need some help on this. Look, it's (Asbestos) a two-parted rock. If you do that (scratches white part) it scratches, but if you take the rock (black part) it don't. I'll see if the nail scratches it (the black part). Yah, it does, so I don't know where to put it (on the hardness table) because, look, you can scratch it (white part) with your fingernail. (When the teachers does not come over to the table, Sam decides to record the asbestiform (white part) result. (Thus, he incorrectly ordered the first two minerals.) (Appendix F, T5/10)

Lack of knowledge results in incorrect decision

Failure to identify and to test for the principal mineral in a given specimen might have contributed to the errors made by many children.

Hardness Variations Within a Mineral

Another factor contributing to the introduction of error into the hardness investigation is that related to the internal structure of the mineral. If the internal molecular structure of a mineral displays some inhomogeneity the direction in which or the face on which an attempt is made to scratch the mineral is of significance with respect to the result achieved. Different hardnesses may, in fact, exist for each direction, depending on whether the mineral is scratched along the grain or across it. As a result of this circumstance, certain minerals may be scratched more easily in one direction than in another. Any of the minerals used in a minerals and rocks unit displaying this characteristic would render the children's task of determining the hardness of those minerals much more difficult.

Precision of Measuring Devices

In addition to the nature of the minerals used in the unit, the precision of the measuring devices used might well have contributed to the nature of the results obtained by the children. The testing implements (fingernail, copper coin, steel nail, file and glass) were imprecise by scientific standards and were not capable of yielding information regarding fine differences in hardness. Consequently, the fingernail (H-2½) would not necessarily discriminate between Graphite (H-2), Manganese ore (H-2½) or Asbestos (H-2½ to 4), nor would the file (H-5½ to 6) differentiate between Anhydrite (H-3½) and Fluorite (H-4); similarly, the glass test might not be fine enough to permit distinction between Pyrite (H-6 to 6½) and Quartz (H-7), and so on. The ambiguous results recorded by the children, therefore, could well have been anticipated given the mismatch between the nature of the hardnesses of the measuring devices and those of the minerals being measured.

Furthermore, it must be noted that nails, files and glass are known to exhibit varying degrees of hardness. Steel nails, for example, might range in hardness from 5½ to 6. If non-steel nails were used, the results could be even more ambiguous. Thus, the choice of particular nails, files or pieces of glass for use by the children in testing for hardness of minerals might well affect the outcome of the exercise.

All of these factors, then, hardness range, minimum hardness intervals, type of measuring device, experimental technique, identification of the principal mineral, coupled with the nature of the minerals, all contribute towards making hardness a very difficult criterion to specify. Nonetheless, if hardness measuring activities are to be developed for use by children, full consideration needs to be given to each factor if the exercise is to be valid, reliable and technically sound.

Factors Acknowledged by Geologists

During the course of their mineral ordering task geologists commented on a variety of factors which they appeared to take into account during their attempt to make sense out of the activity and to complete it in accordance with the requirements set out in the exercise. One geologist was observed to comment on the difficulties associated with identifying the principal mineral: "Once again there is more than one mineral present here and, furthermore, there is more than one variety of a particular mineral present which is going to confuse somebody." Following an explanation about the varieties of the mineral present, about how each might react to a particular testing procedure, and while noting how a person could be misled by certain results, he nonetheless proceeded to test the 'correct' variety of the mineral.

The relative nature of some of the judgements involved ("Hardness is a very relative thing and it's even more difficult to be precise under such crude conditions.") and the imprecision of the testing implements ("Files, you realize, vary quite significantly in hardness from one to another.") also were acknowledged. A distinction was made between scratch hardness and brittleness, the factor at play in each specific situation being identified. And although geologists too were observed to 'feel' minerals, they did so for purposes of determining the presence or absence of a scratch.

The testing techniques used by the professionals revealed a high level of sophistication and a breadth of experience. Each person worked methodically and systematically, reflecting on factors which might be affecting the outcome. They systematically rubbed off after each scratch attempt and often were observed using a magnifying lens to examine the results. Sharp-edged scratching devices and clean testing surfaces were considered mandatory. The inability to obtain a testing surface of adequate size and quality precipitated a comment which indicated how a geologist might normally proceed when required to test such a specimen:

> The black part (Tourmaline) is very brittle of course. Appears to be a single crystal. I'd put 36 (Tourmaline) here (equating it with the hardness of a file). Seems to scratch glass but I have to be careful that I'm not testing with the Feldspar. This is a test one normally would carry out under a binocular microscope. Now I'm unable to get this into a position that I can tell. I can't tell whether I'm scratching it with one or the other.

"Hardness - Like Something you Can't Break": The Curriculum as Perceived by Children

Inspection and analysis of the data gathered during the course of the study revealed that the children's understanding of the concept of hardness of minerals appeared to be associated with several ideas which ranged across a continuum extending from what has been termed experiential or common-sense understanding to that of a more scientific understanding of the nature of the hardness of minerals.

A Common-Sense Understanding of Hardness

An indicator of the child's experiential understanding of mineral hardness was first encountered during the introductory discussion to the unit during which the children's responses to the question, "How would you test the hardness of a mineral?" suggested that they viewed hardness of minerals in a manner somewhat similar to the way in which they viewed the hardness of other common materials, that is, how easily might a material be broken. Some initial responses from the children when questioned about ways to test the hardness of minerals included:

Sam: Hardness — like something you can't break.

Jim: Break them.

Sally: Bang them on the table.

Cathy: Drop them off the table.

Teacher: What if they both broke?

Cathy: Then they'd both be soft.

Since these responses were observed prior to the formal study of minerals (during which time no spontaneous reference to the relationship between scratching and hardness was made by any child) it was inferred that such responses indicated that the children's common-sense understanding of hardness included an element of breaking. This inference was further subtantiated from time to time during class activities when children were observed to relate some personal experiences which included a 'breaking' phenomenon with hardness as was illustrated by Tim's example of why he felt that a nail was harder than a penny:

Tim: I got a hammer once and battered a bunch of pennies -------- Like you can get a hammer, you can (bend a penny) ---- Like I did it before. I ruined a penny, I bashed it all up, but with a nail, it's harder (more difficult to bash up). (Appendix F, T4/4-6)

During the entire course of observation of presentation and implementation of the unit, children were observed to refer to or put into application this breaking aspect, an aspect which they commonly associated with hardness. As a result, and for purposes of this study, this experiential or common-sense understanding of hardness is regarded as being associated with the breaking criterion.

A Scientific Understanding of Hardness

The scientific definition of hardness associates specific meaning with the word hardness, namely the ability of a material to resist scratching. For purposes of this study, then, the understanding of the term "mineral hardness" was linked with the scratching criterion.

Sometimes professionals in the field look for secondary evidence that will help them determine whether or not a mineral had been scratched. Such evidence, for instance, includes feeling for a scratch because the fingers are on occasion more sensitive to a scratch than is the eye, the slight roughness caused by a scratch being felt even though it cannot be seen, although X10 magnifying lenses may assist in this process. Sometimes evidence of scratching may be indicated by the presence of some powder left behind after a scratch attempt (although care has to be taken to ensure a distinction between the powder left by a scracher as opposed to a scratchee) or by the ease with which a mineral is scratched. It is important to remember at all times, however, that this secondary information is collected for the purposes of establishing the presence (or lack) of a scratch and is not to be regarded as an end in itself.

Throughout their involvement in the mineral hardness activity, children were expected to apply the scientific concept of mineral hardness, the meaning of which was quite distinct from the children's general experiential understanding of hardness. It was intended (by the developer of the unit) that children would come to an understanding of a particular precise scientific definition through the need to apply the concept of 'hardness' during the class activities dealing with hardness of minerals. Therefore, a feature of the exercise was that teachers were not required formally to define mineral hardness prior to embarkation upon the activity. In practice neither teacher defined mineral hardness before the exercise was completed, however, both informally referred to the phenomenon as "scratch hardness" or as "resistance to scratching" in the course of discussion during presentation of the unit. The degree to which the children actually accepted and internalized the intended scientific meaning of mineral hardness remained to be determined. Since the Minerals and Rocks unit required children to become involved in the handling and testing of minerals and rocks, their activities with these materials provided a rich source of data for inspection, the primary focus of which was the actual testing of minerals in order to determine their hardness.

A Composite Picture of Testing for Mineral Hardness

The observed inconsistencies in children's behaviour during testing of mineral hardness throughout their study of the Minerals and Rocks unit suggested that an examination be made of the various methods used by children when testing for hardness of minerals. An examination of the available data which included both what children said about testing mineral hardness together with what they actually did in testing for hardness, provided a basis for constructing a flow chart which illustrated the basic elements of the procedures apparently followed by the children in reaching their conclusions (see Figure 4).

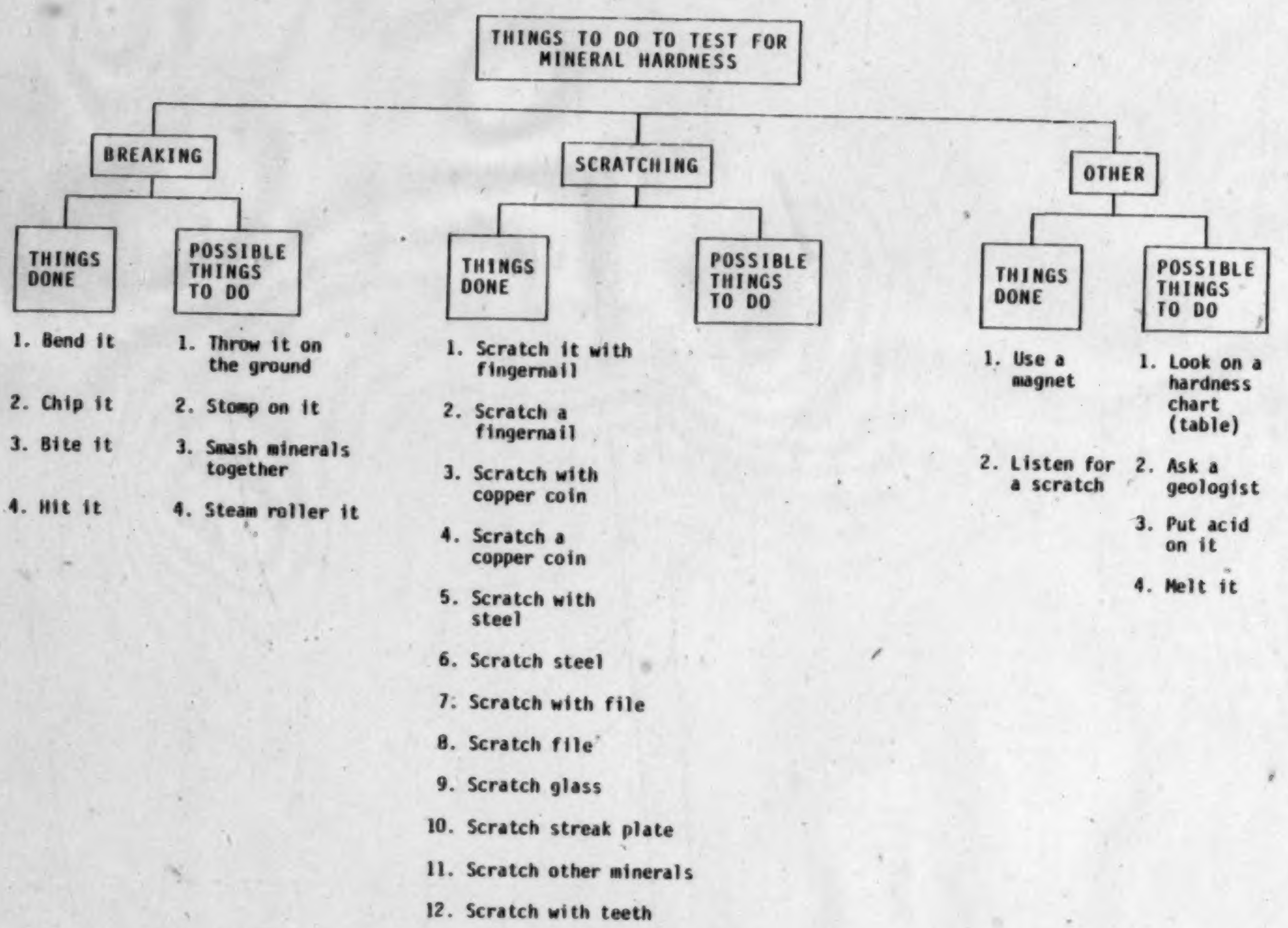

THINGS TO DO TO TEST FOR MINERAL HARDNESS
BREAKING
SCRATCHING
OTHER
THINGS DONE
1. Bend it
2. Chip it
3. Bite it
4. Hit it
POSSIBLE THINGS TO DO
1. Throw it on the ground
2. Stomp on it
3. Smash minerals together
4. Steam roller it
THINGS DONE
1. Scratch it with fingernail
2. Scratch a fingernail
3. Scratch with copper coin
4. Scratch a copper coin
5. Scratch with steel
6. Scratch steel
7. Scratch with file
8. Scratch file
9. Scratch glass
10. Scratch streak plate
11. Scratch other minerals
12. Scratch with teeth
POSSIBLE THINGS TO DO
THINGS DONE
1. Use a magnet
2. Listen for a scratch
POSSIBLE THINGS TO DO
1. Look on a hardness chart (table)
2. Ask a geologist
3. Put acid on it
4. Melt it

Figure 4. Categories of things to do to test for mineral hardness according to the children.

Closer scrutiny of data relating to the children's behaviour suggested that the procedures which they followed in testing for mineral hardness could be grouped in three main categories — 'breaking', 'scratching' and 'others'. It is important to reiterate once again that, from a scientific point of view only the scratching criterion may be accepted, although from the point of view of the children, additional criteria, particularly that of breaking, played an important role in determining the hardness of minerals. In general, children did not show any preference for the scratching criterion above others, but tended to use it often in association with other criteria, including secondary evidence such as depth of scratch, number and size of mineral chips and so forth. My own failure to recognize this crucial distinction being made by the children delayed for several months the final construction of the taxonomy, this being due in part to investigator bias which mitigated against 'seeing' the children's real modus operandi, leading instead, to an interpretation of the children's behaviour in terms of the intended mode of operating, that is, applying the scratching criterion above all else. Once the nature of this obstacle had been recognized other factors began to fall into place.

The 'Breaking' Criterion

In constructing the taxonomy each major possible criterion was examined on the basis of those things actually done by the children when testing for mineral hardness as opposed to those things that the children actually said were possible to do during testing for mineral hardness. As far as the breaking criterion was concerned, the things done and the things which it was possible to do were arranged in order of degrees of vigour ranging from bending to hitting and from stomping to steam-rolling, each test either being a spontaneous suggestion or one used by the children. It was noted that, during the culminating activity of the unit involving hardness of minerals (after six weeks of studying about minerals and rocks) all but one child was observed to apply the breaking criterion at least once in determining mineral hardness and even Sam, the one child who did not, suggested that then hammering might be employed as a last resort. It appeared, therefore, that, for most children, the commonsense idea of hardness, that is breaking, continued to be a factor of importance in the determination of mineral hardness.

The 'Scratching' Criterion

A number of techniques were used by the children in determining mineral hardness which may be included under the heading of the scratching criterion. The first nine of these criteria apparently represented behaviour learned as the result of classroom activity, the remaining three reflecting spontaneous ideas intuitively devised by the children. It is important to note, once more, that while many children applied the scratching criterion in the way that it was formally intended (for example, to determine the presence or lack of a scratch), this was not invariably the case. Often the same children who applied the criterion in the intended manner were later to be seen looking for additional evidence such as depth of scratch or number and size of particles, appearing to use this evidence as the ultimate determiner in differientiating between minerals of varying degrees of hardness, as these typical transcriptions illustrate:

According to Reid, both Fluorite and Apatite scratched steel and both were scratched by the file. When asked why he then decided to place Apatite before Fluorite in order of hardness, Reid gave this reply:

Reid: I guess I just took a guess.

Interviewer: Did you have a hunch?

Assessing depth of scratch

Reid: Yah, because the scratch wasn't as deep.

Interviewer: Could you show me that?

Reid: (Scraping Apatite with the file) The scratch doesn't go very deep. (Scraping Fluorite) That one (Fluorite) doesn't go quite as deep as that (Apatite). (NOTE: in fact, the actual order of hardness of Fluorite and Apatite is just the reverse.) (Appendix H, T18/4)

Chuck appeared to be influenced by the number and size of particles that resulted from chipping with the fingernail. When asked how he would know which was harder Apatite or Halite if both left 'chips' he replied:

Focusing on number and size of particles

Chuck: I would break it and see which chips more. If you break that (Apatite) and it hardly chips, and if you break that one (Halite) and it falls into crumbs and everything.

Interviewer: So, do you look at the size of the chips, how big they are or what do you look at?

Chuck: How big they are.

Interviewer: And if Halite left bigger chips, what would that tell you?

Ease of chipping associated with hardness

Chuck: That it chips easier. (Is "softer" than Apatite.) (Appendix H, T9/2)

Thus, even though a scratching technique was being utilized, the scratching criterion was not necessarily being employed, an important distinction that needed to be recognized.

The 'Other' Criterion

All other techniques utilized (or suggested) by the children as a means of determining mineral hardness such as use of a magnet, melting the mineral or listening for a scratch, were grouped under the 'other' category because, although these represented a variety of techniques, none of them constituted major behavioural patterns. Of the children responding to questions relating to magnets and mineral hardness, one-third said they either used the magnet as part of mineral ordering activity or said it could be used, while another one-third said the magnet had nothing to do with mineral hardness. This dichotomy suggested that both the concept of magnetism and/or the concept of hardness was not fully understood from a scientific point of view. Those children who indicated that magnets were useful in helping to determine the hardness of minerals gave a variety of reasons why this was so:

Hardness associated with brittleness	Tim:	I used it (magnet) to see if they were magnetic and they were magnetic then they would be as tough as a magnet then.
	Tommy:	(After being asked if he used the magnet) I didn't need to use it.
Hardness associated with brittleness and cleavage	Interviewer:	Why not?
	Tommy:	I didn't think any of the rocks were made of metal.
	Interviewer:	Would that help you to determine the hardness — if they were made of metal?

Tommy: Yes. Metal is sort of hard and things like that (the minerals) that aren't made of metal aren't hard.

Indirect use of information to narrow range of possibilities

Bill: (After mentioning that the magnet was of no use in helping him determine the hardness of any of the given minerals) (The magnet didn't help) Because none of the minerals were magnetic.

Interviewer: If they had been magnetic, would that have helped you?

Bill: I'd probably know what it (the mineral) was then and I might know the hardness already.

Although the responses grouped under the 'other' category did not form recurring themes, they were nonetheless important in contributing to a broader picture of the nature of the child's understanding of the concept of mineral hardness.

Once the general methods of testing for mineral hardness had been identified it then became possible to examine both verbal and operational behaviour for evidence which might indicate distinct patterns of understanding of the hardness concept. Since breaking and scratching had already been identified as key elements in the children's mineral testing process, it was anticipated that these factors would, in some way, play a major role with respect to the manner in which children viewed the nature of hardness of minerals in general. In an attempt to elucidate matters relating to this latter factor, an examination was made of both verbal and operational behaviour using all available observational data.

Children's Views of Mineral Hardness

Verbal Descriptions of Mineral Hardness

An inspection of children's verbal descriptions of the nature of mineral hardness revealed the existence of a variety of perspectives ranging from a primarily common-sense (breaking) viewpoint to a predominantly scientific (scratching) approach. Generally, children described mineral hardness in functional terms, that is in terms of what could be done to demonstrate mineral hardness, or the way in which minerals responded to stress or pressure, usually caused by scratching or breaking. Some typical explanations of mineral hardness are illustrated by the following transcribed responses:

Breaking criterion only	Penny:	Generally the hardest is the toughest to break and stronger than the other ones.
Scratching and breaking criterion	Roy:	Well, you can scratch and tear it and it's hard and you can break it.
Scratching criterion only	Bill:	How it can be scratched and how it scratches things.
Scratching criterion with strong emphasis on secondary evidence; functional and intrinsic properties involved	Sam:	How hard it is. How good it's put together. Like how it holds each particle together. Like if it was a really soft mineral then you could just do like this (scratching motion). Then you could see a bunch of little particles here (on the table). But if you took a hard one (mineral) and did that (scratched it), you wouldn't see anything — just one or two little specks. And, ah, if you took an inbetween (mineral), you would scratch it and you could get some or you could scratch it and you didn't get some (particles). It would be either one.

Two of 17 children interviewed gave verbal descriptions related exclusively to the breaking criterion, two other children gave descriptions associated primarily with the scratching criterion and the remaining 13 children gave responses which involved both criterion, suggesting that although the latter group applied the formal definition of hardness they nonetheless continued to be influenced by their past personal experience with respect to hardness in everyday contexts (see Appendix H).

Applied Meanings of Hardness

As previously indicated another clue to the understanding by the children of the meaning of mineral hardness was revealed by way of the methods they employed when testing the hardness of minerals. Those children who primarily described hardness in terms of the breaking criterion also generally used a breaking apporach to the testing of the minerals, an approach which commonly included hitting a mineral with a hammer, chipping off pieces of a mineral with a fingernail, bending minerals or just 'feeling' them. Consonance thus existed between criterion and testing/experimental procedure. This approach (demonstrated exclusively by 12% of the children observed and frequently by 76% of them) was illustrated particularly well by Tim whose verbal and non-verbal behaviour, throughout the entire unit, reflected primarily the breaking point of view:

	First Day	(Justifying why a steel nail was harder than a copper penny after completing a scratch test on both of the materials)
Applying breaking criterion		You can bend it (the nail). If you could stretch a penny I bet you could bend it. (Tries to bend the nail but cannot; hits the penny with the nail)

See, you can see a hole by the maple leaf!

Two days later

(Responding to the question "Can you tell from scratching whether the nail or the penny is harder?")

Language and actions manifesting breaking criteria

See, bend the nail.

(In discussing whether the chalk or the chalkboard is harder.)

It's (chalk) easily grinded.

(Upon receiving a piece of Graphite.) Wow! Number 4 is a weak one! (Noticing the black marks left on his fingers as he feels it.)

One week later

(After trying to cleave some Quartzite by hitting it with a hammer and being asked what he had learned from the experience.)

Associating cleavage with breaking only

It's pretty hard. You really have to give it a slug! You really have to hit it hard. It's very hard!

Five weeks later

(Explaining how he determined the hardness of a given set of minerals that he had just put in order of increasing hardness.)

Breaking viewpoint dominant

Yah, (I used the hammer) so I could see how things broke down. If I pounded this one (Halite) it breaks real easy and if I pound this one (Corundum) it doesn't break as fast.

(Throughout the discussion Tim was observed chipping and bending several in the process of testing their hardness. When he did scratch minerals this was done in order to ascertain whether the mineral would indeed bend or chip, to discover easily how this would occur, rather than attempting to answer the question "Was the mineral scratched or not?")

Sam on the other hand, typified the few students whose behaviour suggested that they too held a breaking point of view at the beginning of the unit but, who, over time realized the true nature of the new concept being presented, used it, and emerged manifesting primarily a scientific approach (scratching) and a scientific point of view relative to mineral hardness.

During the initial hardness activity when many children appeared to experience difficulty in understanding how to proceed, Sam seemed to follow along with little difficulty, first reading the directions provided and then testing as directed. He consistently rubbed off the specimens after each test and examined the surfaces very closely, apparently oblivious to the fact that others were experiencing difficulties. Many of his remarks suggested he was applying the scratching criterion when testing for hardness even though common-sense knowledge influenced his initial reaction to the idea of mineral hardness.

	First day	(Spontaneously suggesting hardness as one property of minerals.)
Applying breaking criterion		Hardness - like something you can't break. Like you have to use so much acid or something.
		(And later in the discussion when children were suggesting ways of testing for hardness.)
Suggesting other criterion		I think I know another way to figure it (hardness) out. Put it in the oven and crank it all the way and see which one melts first.
	Two days later	(While applying the scratching tests as directed.)
Applying scratching criterion		Rub it (penny) off to see if it (nail) scratches the tarnish off or if it is scratched it. (Rubs off.) There, it does scratch it. It's a new penny too, so it doesn't have any tarnish on it.
		(In the process of testing a Tourmaline specimen, talking quietly to himself.)
Using hardness scale and applying scratching criterion		Well, this is really soft (scratching it with his fingernail). Naturally, if you can scratch it with your fingernail --------

It's crumbling (pieces of Tourmaline come off with scratching).

I need a penny. (Proceeding in order with the tests; tries the nail next and then goes on to the file, always applying the scratching criterion.) Yah, it scratched (the glass) and you can't take it off either.

One week later

(During the cleavage activity, Sam also seemed overwhelmed by the force need to fracture a piece of Quartzite.)

Referring to everyday use of hardness

Yah, it's real real hard and it's smooth. Like if you took this (Quartzite) and belted it with a hammer, it's hard to break.

(Sam's behaviour in other activities suggested he associated the hammer with cleavage, not mineral hardness.)

Five weeks later

(Although an element of hardness was associated with cleavage Sam nonetheless differentiated between the 'cleavage' hardness of Quartzite and its 'scratch' hardness.)

Differentiating between cleavage and mineral hardness

Interviewer:	Is cleaving, breaking?
Sam:	Yah, if it breaks into even pieces, it's cleavage. But if it shatters it doesn't — isn't cleavage.
Interviewer:	Does cleavage help you tell hardness (of minerals)?
Sam:	No, I don't think so.
Interviewer:	I see. You mentioned scratching, breaking and cleavage. Did you use any of these to help you determine the hardness (of the given minerals?)
Sam:	Scratching, just scratching.
Interviewer:	How come just scratching?

Determining hardness of minerals by utilizing the hardness scale, using secondary evidence to determing presence of a scratch

Sam: Because to see which would scratch less. Like if you took a penny and you scratched it (a mineral) and it didn't (scratch), and you took it and scratched it on a plate (steel) and you took it to the file and the file scratched it, the file would be the end of the line for it. It wouldn't be able to go any further (hardness determined). But if you took something (a mineral) and it got scratched by the fingernail, then it would be fairly soft. And if it didn't scratch the nail, that would mean that it's kind of soft (between fingernail and nail) and kinda hard and inbetween.

The majority (76%) of the children, however, displayed verbal and operational behaviour which suggested that they adhered simultaneously and in varying degrees, to both the common-sense and to the breaking and the scratching criteria as the situation demanded. In addition, children in this 'inbetween' stage often relied on secondary evidence such as size and number of particles, or amount of force required to break or scratch minerals as a primary basis for decision making, rather than using such information as supporting evidence for the presence (or lack thereof) of a scratch as applied by professionals in the field. Chuck's behaviour typified the modus operandi of children in this category who displayed a similar approach.

First day (Trying to determine order of hardness of penny and nail.)

Associating hardness with breaking

Chuck: The penny (is harder). Nail!! I can't bend a penny. I can bend a nail.

Tim: You can't bend it (nail). If you could stretch a penny I bet you could bend it.

Chuck: Okay. Try and bend the nail. (Both children eventually take to hitting the materials in an attempt to determine their hardness.)

Two days later

(Continuing with the breaking idea.)

See, if you can bend the copper penny. ---- (Conceding) That nail is harder.

Applying the scratching technique randomly

(In testing mineral hardness Chuck applied the scratching criterion as the hardness scale suggests although he does not conduct the tests in the order suggested, using instead a somewhat random approach.)

Teacher, do we get one glass (plate) each? You mean the rock will scratch it? (Tries scratching Chalcopyrite.)

Have you finished with the file? (Gets file and begins filing, not scratching the Chalcopyrite.) Yah, it scratches.

(Later when testing Tourmaline.) Does a steel penny scratch this? (Scratches Tourmaline with the copper penny.) I made a mark and I can't rub it off.

Five weeks later

(During the culminating activity involving ordering of minerals Chuck appeared to use only the scratching criterion but his explanations suggested other criterion also are involved.)

His initial responses to the meaning of mineral hardness indicated the involvement of more than one criterion.

Interviewer: What does hardness of a mineral mean?

Chuck: It's hard ----

Interviewer: What do you mean by the word hard?

Referring to scratching criterion

Chuck: Hard to scratch --------

Interviewer: Hard to scratch ---- Anything else?

Applying breaking criterion

Chuck: Hard to chip.

Interviewer: Chip ----

Chuck: It's pretty hard to break with a hammer.

(Later, in describing how he would differentiate between two minerals, both of which could be 'chipped'.)

Chuck: I would break it and see which chips more. If you break that (Apatite) and it hardly chips and if you break that (Halite) and it falls into crumbs and everything.

Interviewer: So do you look at the size of the chips, at how big they (chips) are or what do you look at?

Utilizing secondary evidence as basis of decision making

Chuck: How big they are.

Interviewer: If they are bigger, what does that tell you?

Chuck: That it chips easier.

(In demonstrating how he determined the hardness of Talc by using a streak plate and other means.)

Interviewer: And what are you trying to find out (by using the streak plate)?

Chuck: Which is the softest.

Interviewer: And did it tell you anything?

Chuck: Yah (points to Talc).

Interviewer: How did you know.

Utilizing secondary evidence and breaking criterion

Chuck: (Streaks talc on plate.) It leaves so much stuff.

Interviewer: How did you know Talc was softer than Apatite?

Chuck: (Demonstrating.) You could break it (Talc) with your hand.

Interviewer: You can break it ----

Chuck: And this one (Apatite) I can't. (Trying to break Apatite with fingers using a chipping motion.) It doesn't chip.

(And later in demonstrating how the file was used.)

Utilizing scratching criterion

Chuck: (Scratching Corundum with the file.) I tried with this end and it doesn't leave a mark on this cause it so hard.

Interviewer: What's so hard?

Chuck: The rock. And this one scratches (scratching Apatite with file). The rock's too soft. Nope, the rock is too hard. It doesn't leave a mark in the rock.

Interviewer: Which is harder then — it didn't leave a mark on #4 (Apatite) or #28 (Corundum).

Chuck: 28 (Corundum).

Interviewer: How do you know that?

Chuck: Cause I can't even scratch it (tries to scratch Corundum three times).

Interviewer: So, it's (Corundum) more difficult to scratch than 4?

Chuck: Yah.

(Throughout the entire discussion Chuck uses the breaking criterion, the scratching criterion and other secondary evidence to determine the hardness of the minerals.)

In summary then, a detailed examination was made of the transcriptions of interviews with the seven primary subjects, the four secondary subjects and six additional children in order to determine the principal viewpoint held by each child with respect to the nature of mineral hardness. A study of both verbal and operational behaviour was made in an attempt to establish the particular viewpoint manifested by individual children, two principal criteria, breaking and scratching forming the basis of the categorization scheme.

Further Validation of Children's Understanding of Mineral Hardness

The recurring pattern of three basic points of view: 'breaking', 'scratching' and 'inbetween', displayed by children throughout their study of the unit, was validated further by way of a common participant observational procedure, namely the proposition of a hypothetical problem. The task, devised by the investigator, was presented to the children during videotaped interviews conducted immediately after the class had completed their formal study of minerals and rocks (see Appendices G and H).

According to Schwartz and Merten (1971):

> Every actor relies upon relatively stable cultural categories to identify the salient roles and any other feature of a social situation relevant to interaction within its confines. Motives arise out of the process whereby shared cognitive and moral categories are brought to bear upon the explication of a particular problematic act. The geneses of meaning, therefore, presupposes those cultural categories which provide common sense labels for the unexceptional aspects of everyday existence. (p.286)

Thus, if breaking, and scratching were the common cultural (cognitive) points of view shared by the children, these could be expected to manifest themselves when the children were confronted with a unique but parallel situation set within the parameters of mineral hardness. In this particular case, children were challenged to place a set of minerals in order of increasing hardness without the aid of testing equipment such as coins, files and so forth. The qualification of completing the task without the aid of testing implements, the latter which could be, and indeed was, utilized by the children for purposes of scratching and/or breaking, challenged the children to apply, primarily, the scratching criterion for solution of the problem. By scratching one mineral with another, in turn, an order of hardness could be established without the use of test instruments. It was assumed, therefore, that the manner in which children approached this problem would provide not only insight into their particular way of viewing mineral hardness, but would be, in fact, a reflection of their 'true' understanding of the concept.

The specific hypothetical problem set was, therefore, the following:

> Supposing you were out in the mountains and you didn't have any of this equipment (files, coins, hammer, and so forth) along. You find these five minerals (Talc, Halite, Fluorite, Apatite and Corundum were provided) and you sit down and think, "I wonder if I can put these minerals in order of increasing hardness, even though I don't have any tools with me." Do you think you could do that? (Appendix H)

Since the children had just completed an ordering activity which included a discussion concerning the meaning of mineral hardness and of how they had gone about ordering the minerals (according to hardness) now being used in the hypothetical problem using a given set of testing equipment, it was assumed that, when presented with the new problem, the children's understanding of mineral hardness would manifest itself again in a way similar to the manner which they had been displaying generally.

The 'Breaking' Point of View

The first point of view, breaking, was once more typified by Tim whose understanding of mineral hardness throughout the study of the unit remained closely associated with the breaking criterion:

Associating hardness with breaking	Tim:	(Responding to the hypothetical problem.) Maybe you could throw it on the ground and see what happens.

Interviewer: And what would that tell you?

Utilizing secondary evidence

Tim: If I threw it (Talc) on the ground and one big piece was there, I could say it was pretty hard. And if a little piece (of Apatite) chipped away, I could say it was harder than that (Talc). And if I threw this (Corundum) and nothing happened I would say this was the hardest of all. And (if I) threw this one (Fluorite) and some broke off and then I threw this (Halite) and some chipped, I could tell you, you know.

Interviewer: Supposing you couldn't throw it. Is there anything else you could do?

Tim: Stamp on them real hard.

Interviewer: Anything else?

Tim: Bash another rock against this rock (bash Apatite against Talc) and then if I bash this on this (Apatite on Halite), it chips and things came out of that --------

Interviewer: Can you do anything besides hitting one rock against another?

Applying a biting technique

Tim: Um ---- maybe bite it.

Interviewer: How would you know by biting which was harder?

Tim: Well, if this one (Talc) snapped in half, I would say this was pretty soft. And if I bite this (Corundum) and nothing happens and this (Fluorite), I bite this and a little comes off ---- and --------

Interviewer: Supposing you bit two of the minerals and nothing happened. How could you tell which was harder (Apatite and Corundum for instance)?

Tim: I'd have to maybe stomp on it.

Interviewer: Try another test? Can you think of any other tests?

Tim: ---- Um ---- No, I can't think of any other tests. (Appendix H, T10/5-6)

It was noted that although Tim had applied a scratching technique while testing minerals during the preceding ordering activity, apparently he did not associate this technique with the scratching criterion, his behaviour in both activities instead strongly reflecting the breaking point of view.

The 'In-Between' Point of View

In the second instance, scratching was an applied criterion, but not the only criterion. In addition to relying on secondary evidence (such as the number of particles produced) as a factor in determining mineral hardness the breaking criterion also was utilized. Chuck and Penny's behaviour typified an approach in which several children utilized scratching, breaking and secondary evidence in order to help them complete the ordering task. Chuck's initial reaction to the presented problem was to pound one of the minerals on the table while, at the same time, suggesting that one mineral could be used to 'smash' another. Although he continued by scratching one mineral on another, using the resulting information for mineral ordering, he did not follow through with this testing procedure, reverting to the breaking criterion (chipping) before applying yet another scratching technique using his teeth:

(After determining by scratching that #4 (Apatite) is softer than #43 (Fluorite).)

Interviewer: How did you decide between these three, #43 (Fluorite), #40 (Halite) and #28 (Corundum)?

Chipping minerals

Chuck: ---- (Picking up Halite.) Well, this one looks like it's got a chip. (Chips Halite with fingernail and puts it down.)

Interviewer: What would you do with #40 (Halite) then?

Chuck: (Putting Halite next to Apatite.) No, I'd trade it (Halite) around with this one (Apatite). So, (the order is) #7 (Talc), #40 (Halite), and #4 (Apatite).

Interviewer: Why?

Chuck: Because that one (Halite) I can chip with my fingernail and that one (Apatite) I can't.

Interviewer: And next?

Chuck: (Picks up Corundum; tries to chip it with his fingernail; puts it between his teeth.)

Interviewer: Are you going to bite it? (Interviewer being concerned with safety and the teeth.)

A novel application of the scratching criterion

Chuck: Nope. (Putting Fluorite behind upper front teeth and strokes out.

Interviewer: Your poor teeth! You're trying to chip it with your teeth?

Chuck: This is softer one (Fluorite) (Repeats with Fluorite and Corundum; compares them.) This leaves a little mark. (Scratching rather than chipping.) (Appendix H, T9/9)

Penny on the other hand, primarily used the scratching technique in order to determine the hardness of minerals while still relying heavily on secondary evidence, such as the number of particles produced, in order to assist her in making finer distinctions between minerals displaying similar hardness. The following passages illustrate the line of thinking she pursued, the first passage being related to her scratching of a specimen of Halite with her fingernail:

Focusing on number of pieces

Penny: I'm not sure about this one (Halite) still. It's hard to scratch with my fingernail. (Continuing to scratch the Halite.) Well, a bit was coming off there, but I still think this (Fluorite) would be the softest because a little bit more came off.

(An later when scratching minerals against each other she said:)

Continuing with number of pieces idea

Penny: Well, if you scratch these two (Apatite and Corundum) and dust came off then you could try this one (Apatite) and some other one (mineral). If you scratched these two (Halite and Fluorite) and stuff came off (it) and you scratched this one (Fluorite) with this one (Apatite) or these two (Apatite and Corundum) and a little stuff came off, then try scratching these two (Fluorite and Corundum) and parts would chip off and there would be scratches on here (Fluorite). (Appendix H, T14/7)

The 'Scratching' Point of View

The third pattern of thinking, primarily applying the scratching criterion, is illustrated by Mike's solution to the problem:

Applying scratching criterion

Mike: Well, you could scratch each other.

Interviewer: Would you like to try that and see what happens?

Mike: (Corundum and Halite) scratches it.

Interviewer: What does that tell you?

Mike: This one (Corundum) is harder than this one (Halite).

Interviewer: And then what would you do?

Mike: Try 4 (Apatite) and 28 (Corundum) (Does so.) It scratches.

Interviewer: Does that tell you anything? What do you know now?

Mike: This one (Apatite) is harder than this one (Halite). Scratch this one (Fluorite on Halite).

Interviewer: What are you going to do now?

Mike: Put this one (Halite) next to this (Talc).

Interviewer: What will you do next?

Continuing with scratching criterion

Mike: Well, scratch each other again. (Apatite on Fluorite; tries a few times.) This one (Apatite) scratches this one (Fluorite) so it's (Fluorite) softer. (Puts Apatite down; picks up Corundum; Corundum on Fluorite.) It (Fluorite) scratches on 28 (Corundum) and 4 (Apatite) would be harder than 43 (Fluorite). So, I'd put 43 (Fluorite) next to this one 40 (Halite). (Order: Talc Halite, Fluorite.) Try this one (Corundum on Apatite). (Rubs off; repeats three times; Apatite on Corundum.) They can't scratch each other.

Interviewer: Why not put them down on the table and do it.

Utilizing secondary evidence

Mike: (Tries again; examines them; Corundum on Apatite.) Don't see anything. (Tries again.) Still don't see anything. This one (Apatite) comes off and this one (Corundum) didn't. I think this one (Apatite) is being scratched.

Interviewer: How can you tell it was being scratched?

Mike: Well, this one's (Apatite) coming off and this (Corundum) isn't. It tells that this (Apatite) can be taken off with this (Corundum) so 28 is harder.

Interviewer:	So what is your order now?
Mike:	This one (Apatite) here and this one (Corundum) here. (Order: 7-Talc, 40-Halite, 43-Fluorite, 4-Apatite, and 28-Corundum.) (Appendix H, T17/5-6)

All of the children who were presented with the hypothetical problem were able to identify Talc as the softest mineral, although they did so with the aid of a fingernail rather than by scratching the Talc with other minerals. Only 60% of the children, however, were able to suggest a technique that would allow them to order the four remaining minerals, namely that of scratching one mineral on another.

The results obtained by those children who were able to think of and apply the method of determining hardness are recorded in Table 8. In addition to identifying Talc as the softest mineral all of these children accurately inferred that Halite (H-2) was the second softest mineral because it was scratched by Fluorite (H-5), Apatite (H-6) and Corundum (H-9). Most of the children also accurately observed that Fluorite (H-5) was scratched by Apatite (H-6) and Corundum (H-9), thus making it the next hardest mineral. Since Apatite was scratched only by Corundum, it was the next hardest mineral followed lastly by Corundum, the hardest mineral.

The mineral Fluorite (H-5) emerged as the main source of error for several children who observed that it scratched both Apatite (H-6) and Corundum (H-9), minerals that were harder than itself. Once again failure to accurately distinguish between the 'scratcher' and the 'scratchee' allowed some of those children to make inaccurate inferences. In addition, it also appeared that some

Table 8

Children's 'Scratch' Results Obtained By Scratching One Mineral on Another

'Scratchee'	'Scratcher'					
	Fingernail	#7[a]	#40	#43	#4	#28
Mineral #7 Talc H-1	C D G $\underline{M}$ N R S $\underline{R}$ L $\underline{c}$ $\underline{W}$ T				N L	
Mineral #40 Halite H-2				M R L $\underline{R}$	D M L $\underline{R}$	D M L
Mineral #43 Fluorite H-5					B R L $\underline{R}$	D $\underline{M}$ P L $\underline{R}$
Mineral #4 Apatite H-6				Ⓓ[b]Ⓒ		D M B N P L R
Mineral #28 Corundum H-9				ⓇⓅ	Ⓛ	

Note. $\underline{c}$=Candy; C=Chuck; D=Darla; G=Gerry; L=Laurie; $\underline{M}$=Mike; N=Nan; P=Penny; $\underline{R}$=Reid; R=Roy; S=Sam; T=Tommy; $\underline{W}$=Wanda.

[a] Numbers given are mineral numbers.

[b] ○ - Inaccurate Inference.

children continued to be influenced by the results of their initial order that had been obtained by the aid of testing implements. Penny for example, had inaccurately placed Corundum next to Talc in order of hardness because the coin left a copper mark on the surface when scratched. Similarly, when Fluorite left a mark on Corundum she did not attempt to rub it off and immediately concluded that the Fluorite actually had scratched the Corundum.

Those children who obtained a different order of hardness at the end of the hypothetical activity were asked which method they thought was the more accurate, the initial one which utilized test instruments or the method of scratching one mineral on another. Four of five children said they thought the utilization of testing implements enabled them to make a more accurate ordering, thus indicating a strong affinity for the method presented in class as the more 'correct' method. On the other hand, Reid one of two children who thought that scratching one mineral on another was the more accurate method, gave a reason which suggested he was not as bound to the procedures taught in class. His response:

> "You're testing them (minerals) against rocks, the same rocks-not against other things." (Appendix H, T18/5)

reflected a more sophisticated and independent assessment of the two methods. Reid appeared to realize that the method of scratching one mineral on another eliminated complicating variables and enabled him to get on with the problem and solve it more expediently.

In summary, it may be noted that those children who associated hardness of minerals with breaking attempted to solve the problem presented to them by applying variations of the breaking criterion. A second group of children who believed that hardness was related to several possible factors also used more than one criterion in order to solve the problem, often relying on secondary evidence to assist them in establishing the order of hardness of the minerals. A third group of children, those who generally associated hardness with scratching predominantly used this latter criterion in order to solve the problem presented.

In general, those children (40%) who did not come up with a solution to the problem and were nevertheless able to identify the softest mineral, Talc, by applying the fingernail test or by 'feeling' (bending) the mineral. These children seemed to rely upon the need for a hardness scale and the availability of testing equipment and, when this was not available as an option, they were unable spontaneously to devise a scratch test through which the remaining four minerals could be utilized for scratching against one another in order to determine the relative hardness of the given minerals. This outcome might be expected to emerge from children who had not yet fully adopted a scientific point of view regarding mineral hardness but furthermore tends to substantiate the observations made during the course of other hardness activities in which children from the in-between group continued to determine mineral hardness by means of application of a variety of criteria. There was, however, one exception to this. Sam, who had applied the scratching criteria very consistently throughout the study of mineral hardness, was unable to conceive of the mineral scratching test as a means to a solution of the new problem. He also seemed to focus on the need for the provision of testing implements and when pressed for alternate solutions to the problem, abandoned the scratching criterion as the basis for his approach and went so far as to suggest a breaking solution and even a 'colour' solution to the problem:

Interviewer: (After giving the hypothetical problem) Can you do that (order the minerals) without using any equipment?

Sam: Pretty hard.

Interviewer: Why?

Applying scratching and breaking criteria

Sam: Cause you wouldn't be able to see if it scratches or nothing. You could tell it this (Talc) was the softest (bending it) cause you can break it, so you put that down there (puts Talc aside indicating it is the softest). But these ones (other minerals) would be pretty hard (to order).

Interviewer: Is there anything else you could do?

Sam: (Lining up remaining minerals.) I don't think so (studying them) — besides putting these in a sack and taking them back to the city (presumably so they could be tested there).

Interviewer: What are you trying to do now?

Continuing with breaking criterion; suggesting colour criterion

Sam: (Trying to break the remaining minerals) See if it would break or something. Just take it and go like that. But they're all pretty hard. This (Corundum) looks like it's harder than the others ---- cause it's darker.

Interviewer: What does darkness have to do with hardness?

Associating dark colours with metals

Sam: Sometimes when a mineral is really really (dark), it is strong.

Interviewer: The colour has something to do with it?

Sam: Sometimes -------- (During the lustre activity dark coloured minerals were linked with metallic minerals.)

Interviewer: Can you think of anything else you could do besides breaking them with your hands?

Sam: I can't think of anything. That's all you could do. (Appendix H, T8/10)

Although Sam's classroom behaviour had indicated a consistent application of the scratching criterion, apparently he had not completely assimilated the significance of the true nature of the hardness test and, therefore, was unable to conceive of a solution based upon the scratching criterion when confronted with the hypothetical problem. Consequently, Sam's behaviour could not be categorized exclusively as scratching although he appeared, as did several other children, to be very close to manifesting an exclusively scientific point of view.

Circling the 'Right' Answer

The examination of class quiz results revealed a pattern which appeared contrary to children's belief systems, that is, their test responses were not congruent with what they were observed to say and do with regard to mineral hardness during class and post-unit activities. In both classrooms children's understanding of the hardness concept was ascertained through the use of a teacher-devised multiple choice item which read:

Circle the best answer: The hardness of a mineral is:

(i) its ability to resist scratching

(ii) the ease with which it breaks

(iii) related to the number of pieces it breaks into when hit by a hammer

With few exceptions most children circled response (i), the 'correct' answer. Regardless of whether or not a child's understanding of mineral hardness reflected essentially that of a 'breaker', a 'scratcher' or somewhere 'in-between', most of them recorded in the same way. Although the reasons for this might be found by addressing some of the concerns associated with multipe-choice testing in general, other possibilities more generally within the scope of this study also come to mind and can be examined.

It was noted that among the possible responses listed for the question about hardness both the scratching point of view (response i) and the breaking point of view (responses ii and iii) were represented. Thus, it might be expected that children whose viewpoints of mineral hardness contained a strong breaking element would select one of the two 'breaking' alternatives. This, however, did not occur with most children selecting the scratching response. Tim, the child who remained a complete 'breaker' throughout the study of the unit illustrates this point. He reacted to the item in an unanticipated manner. Upon receiving his test paper he quickly began to scan it stopping almost immediately to focus on the hardness question, "Hey, I know this one!" he said excitedly in a loud whisper and quickly circled the 'correct' answer. "This is easy!"

In answering this question Tim and others seemed to apply some kind of 'knowledge' which enabled them to identify the preferred response regardless of whether or not it accurately reflected their understanding of the concept. How did the children know which response was the acceptable one? Was a 'game' of test-taking involved here? If so, what were its rules? Because this discrepancy was not discovered until after the data collection process had been completed, it was impossible to return to the children and ask them about it and thus to pursue the matter further. Nonetheless, this discrepancy is important because of the questions it raises, and the fact remains that although there was congruency between how children talked about the concept and how they applied it during everyday activities, there appeared to be little congruency between their true understanding of the concept and their response to the test item. This situation again raises a flag of caution in that it would be easy for a teacher to infer from such test results that the children did indeed understand the hardness concept as it was intended when clearly in this instance, such inferences would not be warranted.

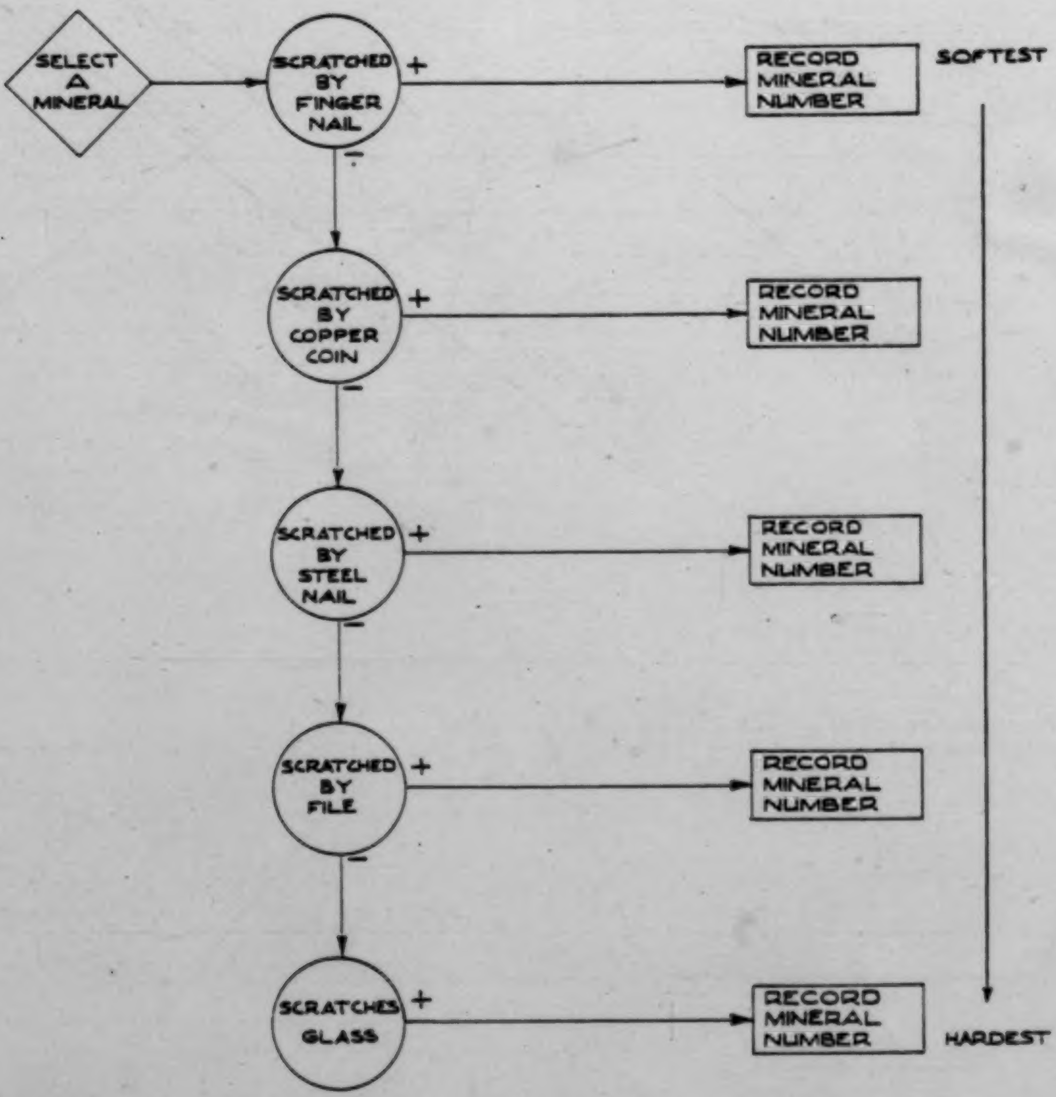
"If Nothing Else Works, Smash it": The Curriculum as Applied by Children

Strategies Employed in Determination of Orders of Hardness

The Intended Strategy

The general strategy for determining the order of hardness of a given set of five minerals as intended by the developer and as described by the teachers to the classes are manifested within the set of rules which children were asked to apply when carrying out the tests for mineral hardness. For the purposes of simplicity and clarity these rules have been set out graphically in the form of a flow chart (see Figure 5) adapted from a decision making model developed by Spradley (1972). Ideally, when applying the scratch rule for determining hardness of minerals, two responses are possible at each stage, a positive response indicating the production of a scratch and a null response indicating the lack of a scratch production. The teachers recommended that each time a mineral was tested this particular testing sequence (the intended sequence) be followed. This formal sequence includes the criteria and rules for determining one of the two possible results.

In the flow chart, each circle indicates the performance of an operation. The arrows indicate data which should be recorded following a YES (+) response or indicate new operations which should be performed following a NO (-) response. For example, if a given mineral is scratched by a fingernail, the number of that mineral is recorded (see Appendix D, student sheet MR2); if the mineral cannot be scratched by the fingernail, the next test, scratching the mineral with a copper coin is attempted. If the mineral is scratched by the coin, the number is recorded, if not, then the nail test is tried next and so on until a positive scratch test results. Each mineral is tested in turn in this way and in the same sequence, beginning always with the fingernail test and working through the intended sequence. It is to be noted at this point that this test differs significantly in sensitivity and detail from that employed by professional geologists in their application of the Mohs Scale of Hardness.


SELECT A MINERAL
SCRATCHED BY FINGER NAIL
SCRATCHED BY COPPER COIN
SCRATCHED BY STEEL NAIL
SCRATCHED BY FILE
SCRATCHES GLASS
+
−
RECORD MINERAL NUMBER
SOFTEST
HARDEST

(+) = YES
(−) = NO

Figure 5: Intended strategy to be applied for the determination of the order of hardness of a given mineral according to the Minerals and Rocks unit.

One operational complication which arose during the implementation of this exercise in the classroom was associated with a discrepancy which arose between intent and reality with respect to the mineral specimens themselves. It had been the intent of the author of the exercise to present each child with a set of minerals, each of which displayed a hardness distinctly different from that of the other minerals in the set. In reality, the differences in hardness between the minerals provided was not as clearly determinable as was desirable, thus some doubts and confusions arose, and the sought after demonstration of an 'order of hardness' emerging from the set sometimes was not achieved.

The Actual Strategies

Observation of activities conducted at the culmination of the unit and recorded on videotape provided the observational data for mapping and identifying the actual strategies used by 17 children in ordering a set of minerals according to hardness (see Appendix H). Initial viewing of the videotape showed children working through tasks in a rather unstructured manner, seemingly selecting testing implements on impulse. In an attempt to determine if any order in fact existed within this apparent chaos, all of the activities of each child throughout the duration of the ordering exercise were recorded. This information was then transposed into a symbolic form using as a framework of reference the flow chart from the ideal strategy model. Upon examination of these flow charts it soon became apparent that the actual operations performed by the children departed considerably from the strategy intended, a major variation in procedure being the inclusion by most children of a greater number of operations at each stage of the testing process, rather than the simpler, one operation, direct yes (+) or no (-) approach which had been intended to form the basis of the procedure. Consequently, in order to capture these variations, modifications in the mode of entry in the flow chart illustrating the intended strategy were introduced. Flow charts illustrating the actual strategies used by the children are presented in Figures 6-22. For purposes of brevity, mineral specimens are referred to by number: Talc = 7, Halite = 40, Fluorite = 43; Apatite = 4, and Corundum = 28. The flow of operations shown on each chart follows the order in which each child tackled the problem.

In these operational flow charts the letters H, F, M, CC, S and SP indicate the particular tool used by the child to test a mineral; H = hammer, F = file, M = magnet, CC = copper coin, S = piece of steel, and SP = streak plate. Each diamond represents the test being employed by the child while each circle represents a step in the testing process at that stage, while illustrating the sequence in which information is being processed. The flow of operations performed is represented by the sequence of rows connected by arrows, inferences drawn being represented by rectangular boxes, those with jagged edges depicting the terminal points of sequences of reasoning which did not appear to lead obviously to an immediate inference or conclusion. Conclusions or inferences of a definite, terminal type were recorded in square boxes. Occasionally, (+) and (-) signs are recorded to the right of a circle, indicating either a positive or a negative test result as determined by the child. The nature of

Symbols Used in Figures 6-22

◇ - testing stage

⊘ - testing step

▭ - inferences

▭ - inference uncertain

□ - conclusions; recorded in boxes, ranging from Box 1, noting the softest mineral, to Box 5, noting the hardest mineral.

- - - ► - sequence of testing operation

——► - sequence of inferences

+ - positive test result acknowledged

- - negative test result acknowledge ('nothing happened')

FN - fingernail

CC - copper coin

S - steel

F - file

H - hammer

SP - streak plate

M - magnet

7 - Talc

40 - Halite

43 - Fluorite

4 - Apatite

28 - Corundum

H on 7 - See above for (H) and (7). H on 7 refers to an implement used to 'test' a mineral for hardness.

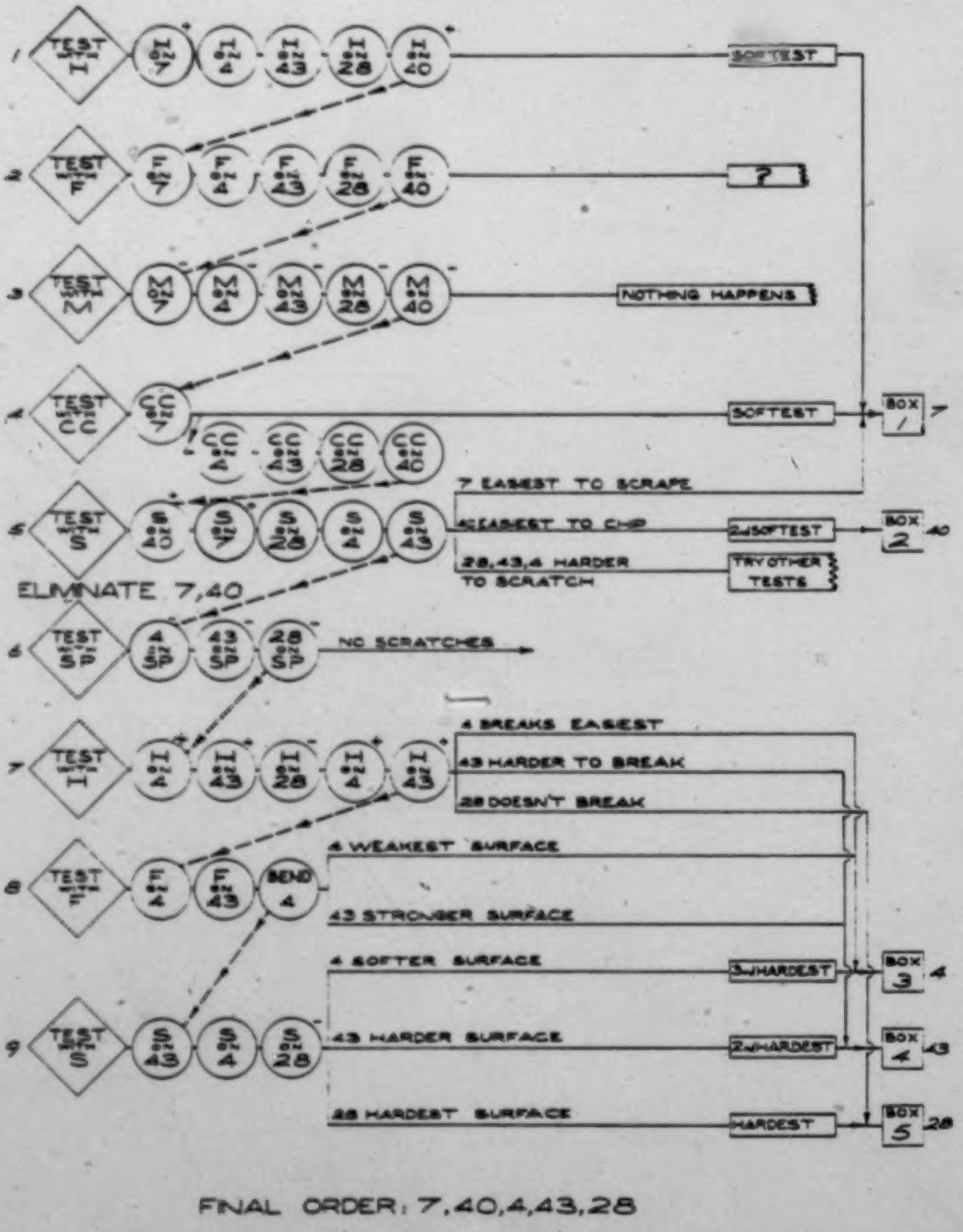

1 TEST WITH H
H ON 7
H ON 4
H ON 43
H ON 28
H ON 40
SOFTEST
2 TEST WITH F
F ON 7
F ON 4
F ON 43
F ON 28
F ON 40
?
3 TEST WITH M
M ON 7
M ON 4
M ON 43
M ON 28
M ON 40
NOTHING HAPPENS
4 TEST WITH CC
CC ON 7
CC ON 4
CC ON 43
CC ON 28
CC ON 40
SOFTEST
BOX 1
7
5 TEST WITH S
S ON 40
S ON 7
S ON 28
S ON 4
S ON 43
7 EASIEST TO SCRAPE
40 EASIEST TO CHIP
2nd SOFTEST
BOX 2
40
28,43,4 HARDER TO SCRATCH
TRY OTHER TESTS
ELIMINATE 7,40
6 TEST WITH SP
4 ON SP
43 ON SP
28 ON SP
NO SCRATCHES
7 TEST WITH H
H ON 4
H ON 43
H ON 28
H ON 4
H ON 43
4 BREAKS EASIEST
43 HARDER TO BREAK
28 DOESN'T BREAK
8 TEST WITH F
F ON 4
F ON 43
BEND 4
4 WEAKEST SURFACE
43 STRONGER SURFACE
9 TEST WITH S
S ON 43
S ON 4
S ON 28
4 SOFTER SURFACE
3rd HARDEST
BOX 3
4
43 HARDER SURFACE
2nd HARDEST
BOX 4
43
28 HARDEST SURFACE
HARDEST
BOX 5
28
FINAL ORDER: 7,40,4,43,28

Figure 6. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Tim.

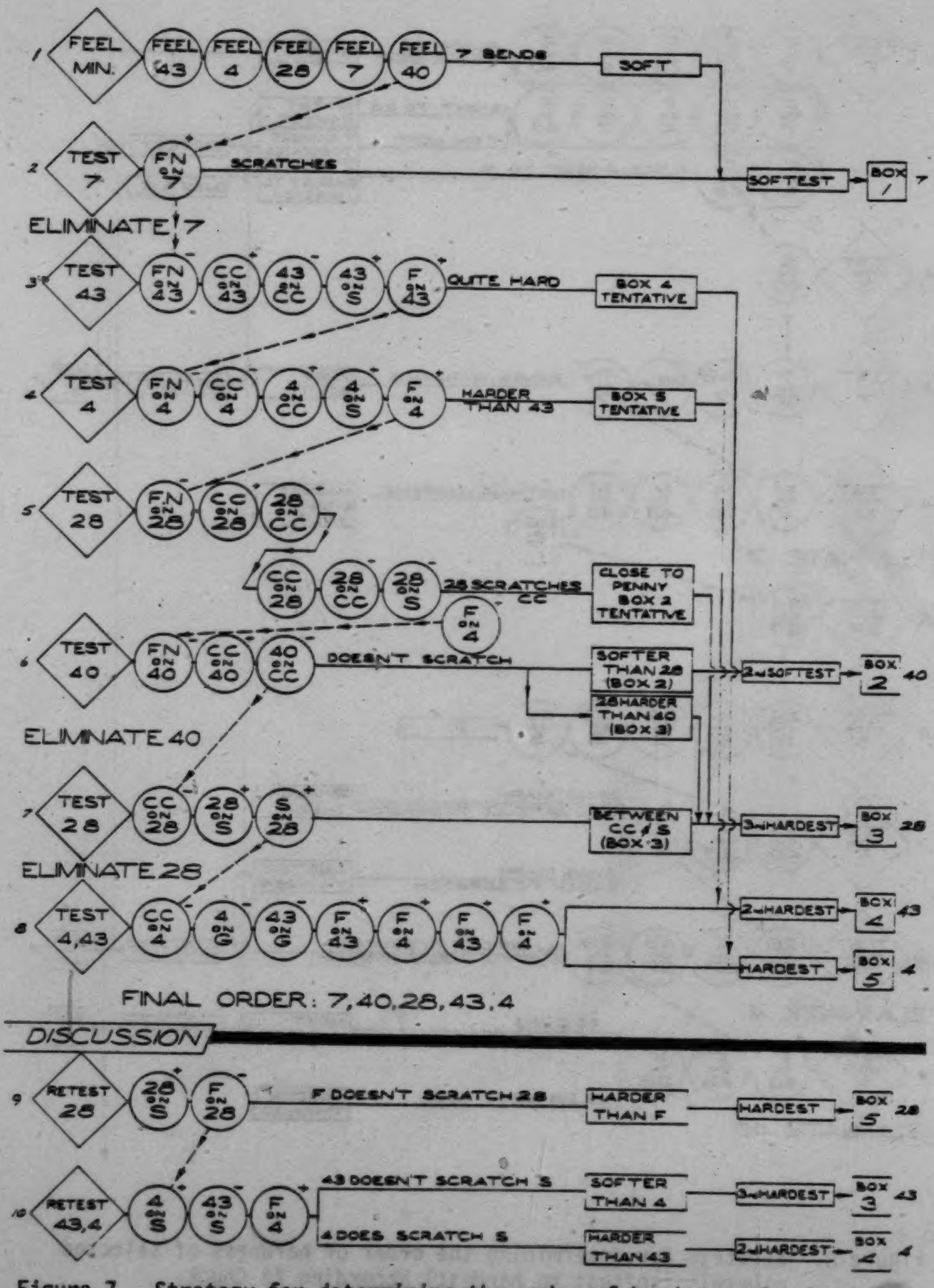

1
FEEL MIN.
FEEL 43
FEEL 4
FEEL 28
FEEL 7
FEEL 40
7 BENDS
SOFT
2
TEST 7
FN ON 7
SCRATCHES
SOFTEST
BOX 1
7
ELIMINATE 7
3
TEST 43
FN ON 43
CC ON 43
43 ON CC
43 ON S
F ON 43
QUITE HARD
BOX 4 TENTATIVE
4
TEST 4
FN ON 4
CC ON 4
4 ON CC
4 ON S
F ON 4
HARDER THAN 43
BOX 5 TENTATIVE
5
TEST 28
FN ON 28
CC ON 28
28 ON CC
CC ON 28
28 ON CC
28 ON S
28 SCRATCHES CC
CLOSE TO PENNY BOX 2 TENTATIVE
F ON 4
6
TEST 40
FN ON 40
CC ON 40
40 ON CC
DOESN'T SCRATCH
SOFTER THAN 28 (BOX 2)
28 HARDER THAN 40 (BOX 3)
2nd SOFTEST
BOX 2
40
ELIMINATE 40
7
TEST 28
CC ON 28
28 ON S
S ON 28
BETWEEN CC & S (BOX 3)
3rd HARDEST
BOX 3
28
ELIMINATE 28
8
TEST 4,43
CC ON 4
4 ON G
43 ON G
F ON 43
F ON 4
F ON 43
F ON 4
2nd HARDEST
BOX 4
43
HARDEST
BOX 5
4
FINAL ORDER: 7,40,28,43,4
DISCUSSION
9
RETEST 28
28 ON S
F ON 28
F DOESN'T SCRATCH 28
HARDER THAN F
HARDEST
BOX 5
28
10
RETEST 43,4
4 ON S
43 ON S
F ON 4
43 DOESN'T SCRATCH S
SOFTER THAN 4
3rd HARDEST
BOX 3
43
4 DOES SCRATCH S
HARDER THAN 43
2nd HARDEST
BOX 4
4

Figure 7. Strategy for determining the order of hardness of selected minerals according to Sam.

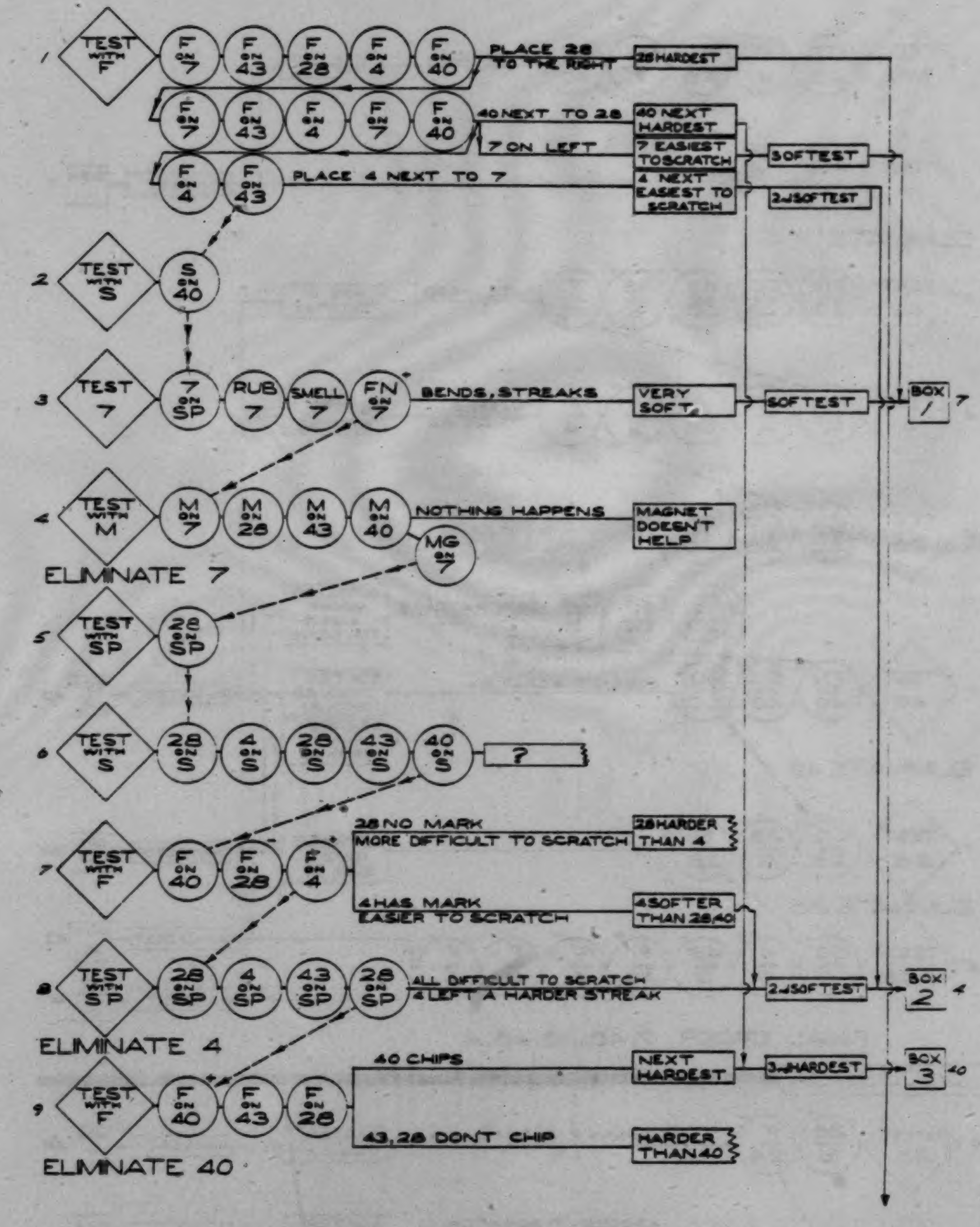

1
TEST WITH F
F ON 7
F ON 43
F ON 28
F ON 4
F ON 40
PLACE 28 TO THE RIGHT
28 HARDEST
F ON 7
F ON 43
F ON 4
F ON 7
F ON 40
40 NEXT TO 28
40 NEXT HARDEST
7 ON LEFT
7 EASIEST TO SCRATCH
SOFTEST
F ON 4
F ON 43
PLACE 4 NEXT TO 7
4 NEXT EASIEST TO SCRATCH
2nd SOFTEST
2
TEST WITH S
S ON 40
3
TEST 7
7 ON SP
RUB 7
SMELL 7
FN ON 7
BENDS, STREAKS
VERY SOFT
SOFTEST
BOX 1
7
4
TEST WITH M
M ON 7
M ON 28
M ON 43
M ON 40
NOTHING HAPPENS
MAGNET DOESN'T HELP
MG ON 7
ELIMINATE 7
5
TEST WITH SP
28 ON SP
6
TEST WITH S
28 ON S
4 ON S
28 ON S
43 ON S
40 ON S
?
7
TEST WITH F
F ON 40
F ON 28
F ON 4
28 NO MARK
MORE DIFFICULT TO SCRATCH
28 HARDER THAN 4
4 HAS MARK
EASIER TO SCRATCH
4 SOFTER THAN 28,40
8
TEST WITH SP
28 ON SP
4 ON SP
43 ON SP
28 ON SP
ALL DIFFICULT TO SCRATCH
4 LEFT A HARDER STREAK
2nd SOFTEST
BOX 2
4
ELIMINATE 4
9
TEST WITH F
F ON 40
F ON 43
F ON 28
40 CHIPS
NEXT HARDEST
3rd HARDEST
BOX 3
40
43, 28 DON'T CHIP
HARDER THAN 40
ELIMINATE 40

Figure 8. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Chuck.

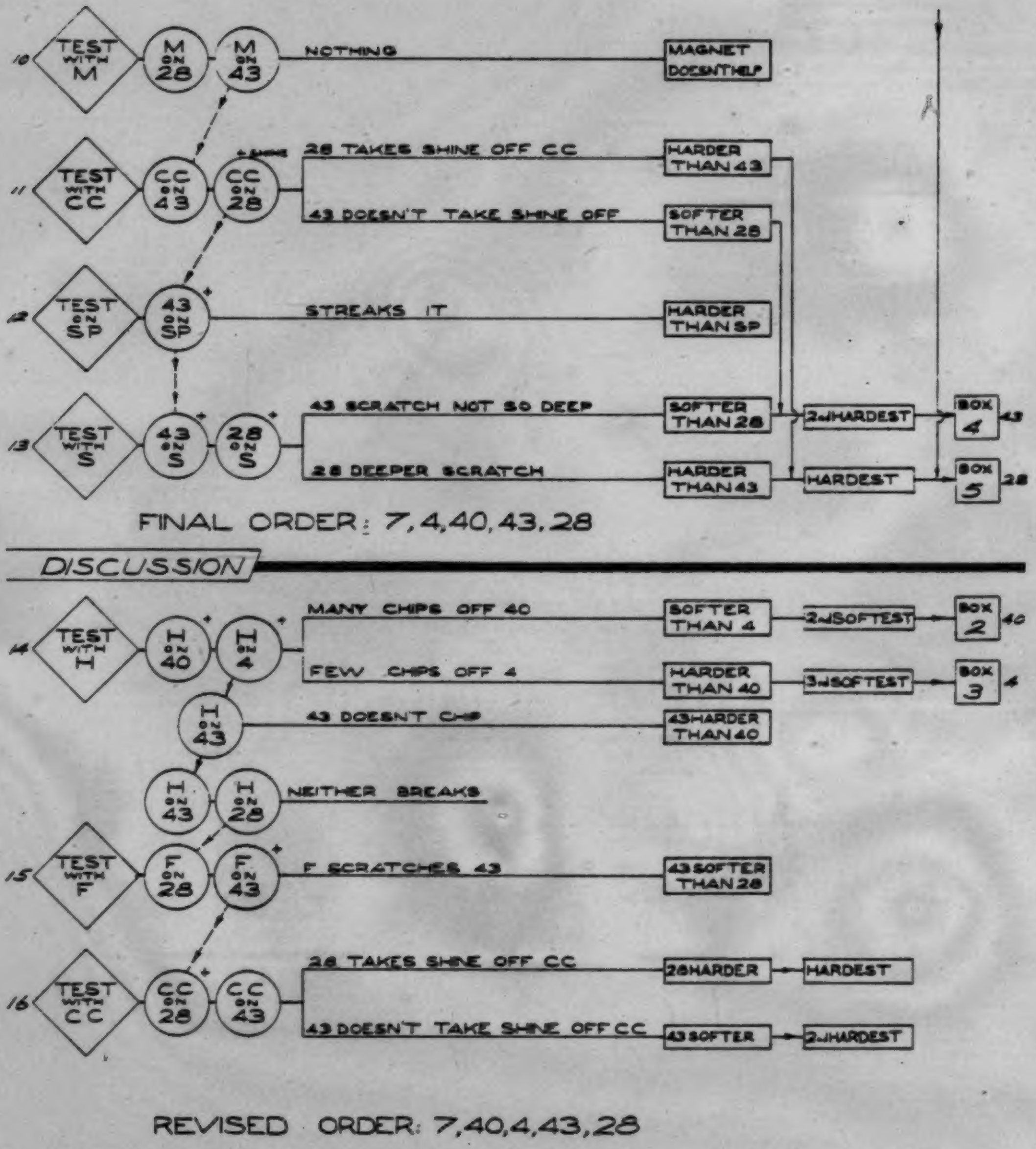

10
TEST WITH M
M ON 28
M ON 43
NOTHING
MAGNET DOESN'T HELP
11
TEST WITH CC
CC ON 43
CC ON 28
28 TAKES SHINE OFF CC
HARDER THAN 43
43 DOESN'T TAKE SHINE OFF
SOFTER THAN 28
12
TEST ON SP
43 ON SP
STREAKS IT
HARDER THAN SP
13
TEST WITH S
43 ON S
28 ON S
43 SCRATCH NOT SO DEEP
SOFTER THAN 28
2nd HARDEST
BOX 4
43
28 DEEPER SCRATCH
HARDER THAN 43
HARDEST
BOX 5
28
FINAL ORDER: 7,4,40,43,28
DISCUSSION
14
TEST WITH H
H ON 40
H ON 4
MANY CHIPS OFF 40
SOFTER THAN 4
2nd SOFTEST
BOX 2
40
FEW CHIPS OFF 4
HARDER THAN 40
3rd SOFTEST
BOX 3
4
H ON 43
43 DOESN'T CHIP
43 HARDER THAN 40
H ON 43
H ON 28
NEITHER BREAKS
15
TEST WITH F
F ON 28
F ON 43
F SCRATCHES 43
43 SOFTER THAN 28
16
TEST WITH CC
CC ON 28
CC ON 43
28 TAKES SHINE OFF CC
28 HARDER
HARDEST
43 DOESN'T TAKE SHINE OFF CC
43 SOFTER
2nd HARDEST
REVISED ORDER: 7,40,4,43,28

Figure 8. Continued

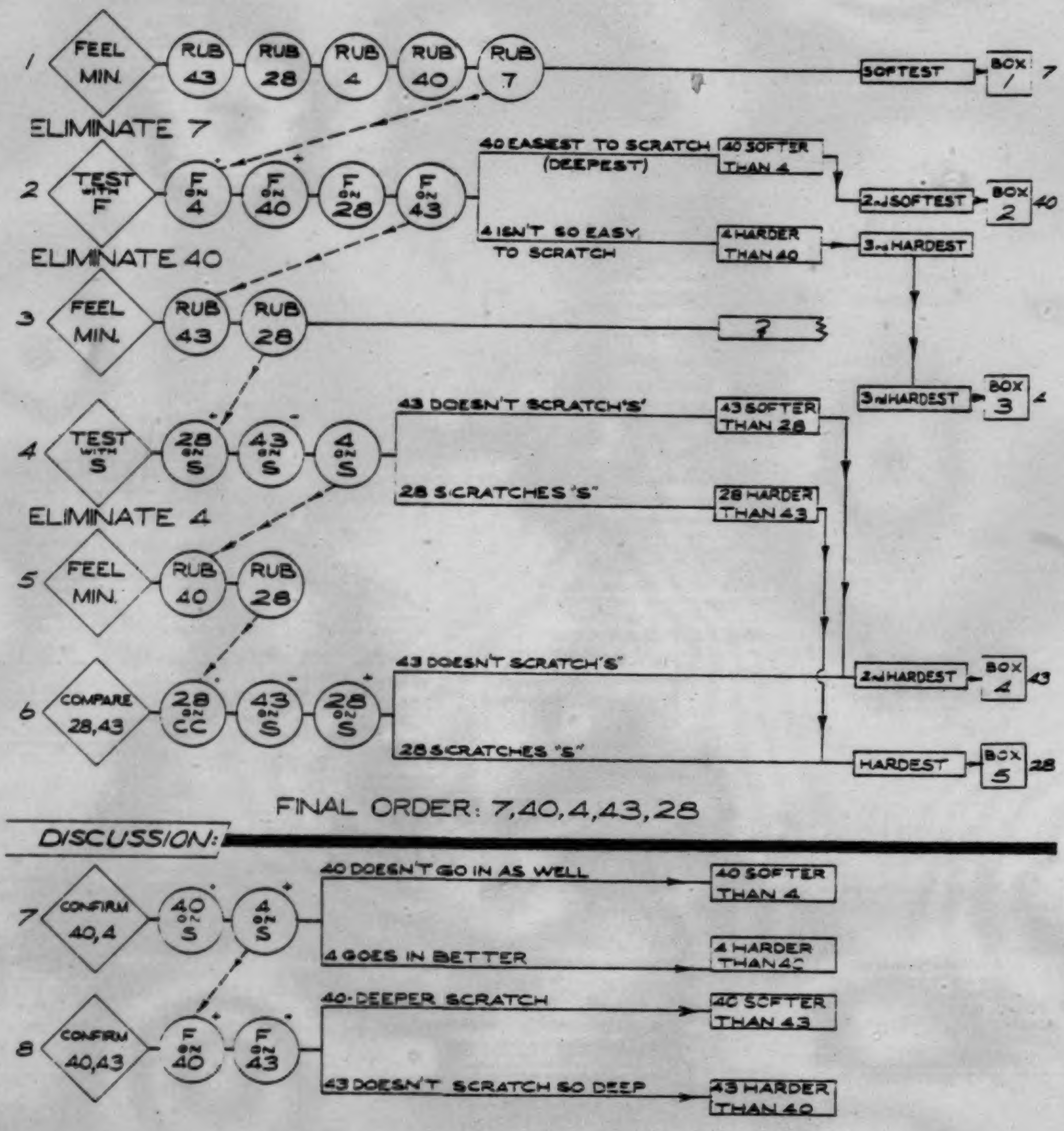

1
FEEL MIN.
RUB 43
RUB 28
RUB 4
RUB 40
RUB 7
SOFTEST
BOX 1
7
ELIMINATE 7
2
TEST WITH F
F ON 4
F ON 40
F ON 28
F ON 43
40 EASIEST TO SCRATCH (DEEPEST)
40 SOFTER THAN 4
4 ISN'T SO EASY TO SCRATCH
4 HARDER THAN 40
2ND SOFTEST
BOX 2
40
3RD HARDEST
ELIMINATE 40
3
FEEL MIN.
RUB 43
RUB 28
?
4
TEST WITH S
28 ON S
43 ON S
4 ON S
43 DOESN'T SCRATCH 'S'
43 SOFTER THAN 28
28 SCRATCHES "S"
28 HARDER THAN 43
3RD HARDEST
BOX 3
4
ELIMINATE 4
5
FEEL MIN.
RUB 40
RUB 28
6
COMPARE 28,43
28 ON CC
43 ON S
28 ON S
43 DOESN'T SCRATCH 'S'
28 SCRATCHES "S"
2ND HARDEST
BOX 4
43
HARDEST
BOX 5
28
FINAL ORDER: 7,40,4,43,28
DISCUSSION:
7
CONFIRM 40,4
40 ON S
4 ON S
40 DOESN'T GO IN AS WELL
40 SOFTER THAN 4
4 GOES IN BETTER
4 HARDER THAN 40
8
CONFIRM 40,43
F ON 40
F ON 43
40-DEEPER SCRATCH
40 SOFTER THAN 43
43 DOESN'T SCRATCH SO DEEP
43 HARDER THAN 40

Figure 9. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Roy.

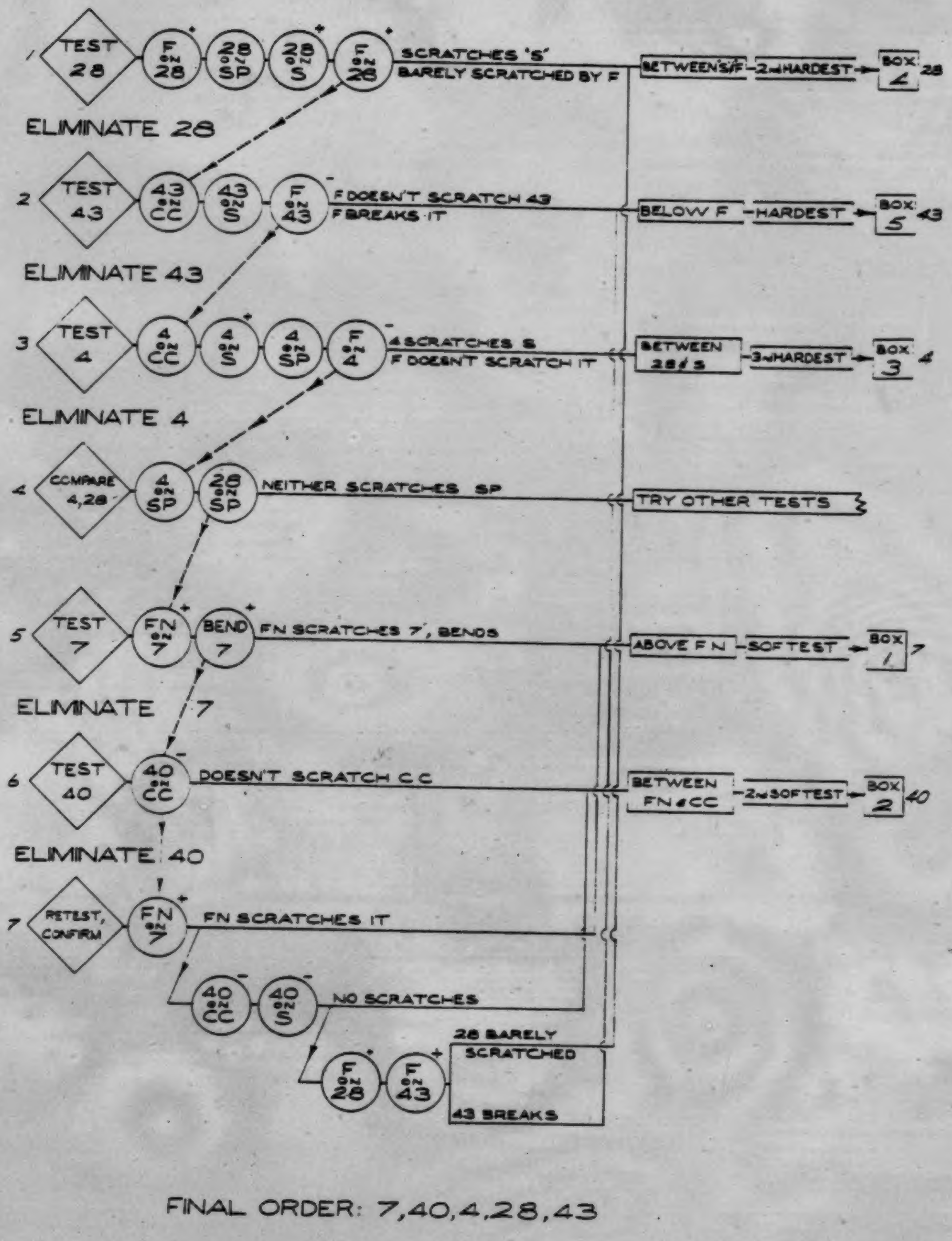

1
TEST 28
F ON 28
28 ON SP
28 ON S
F ON 28
SCRATCHES 'S'
BARELY SCRATCHED BY F
BETWEEN S/F
2nd HARDEST
BOX 4
28
ELIMINATE 28
2
TEST 43
43 ON CC
43 ON S
F ON 43
F DOESN'T SCRATCH 43
F BREAKS IT
BELOW F
HARDEST
BOX 5
43
ELIMINATE 43
3
TEST 4
4 ON CC
4 ON S
4 ON SP
F ON 4
4 SCRATCHES S
F DOESN'T SCRATCH IT
BETWEEN 28 & S
3rd HARDEST
BOX 3
4
ELIMINATE 4
4
COMPARE 4,28
4 ON SP
28 ON SP
NEITHER SCRATCHES SP
TRY OTHER TESTS
5
TEST 7
FN ON 7
BEND 7
FN SCRATCHES 7, BENDS
ABOVE FN
SOFTEST
BOX 1
7
ELIMINATE 7
6
TEST 40
40 ON CC
DOESN'T SCRATCH CC
BETWEEN FN & CC
2nd SOFTEST
BOX 2
40
ELIMINATE 40
7
RETEST, CONFIRM
FN ON 7
FN SCRATCHES IT
40 ON CC
40 ON S
NO SCRATCHES
F ON 28
F ON 43
28 BARELY SCRATCHED
43 BREAKS
FINAL ORDER: 7,40,4,28,43

Figure 10. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Darla.

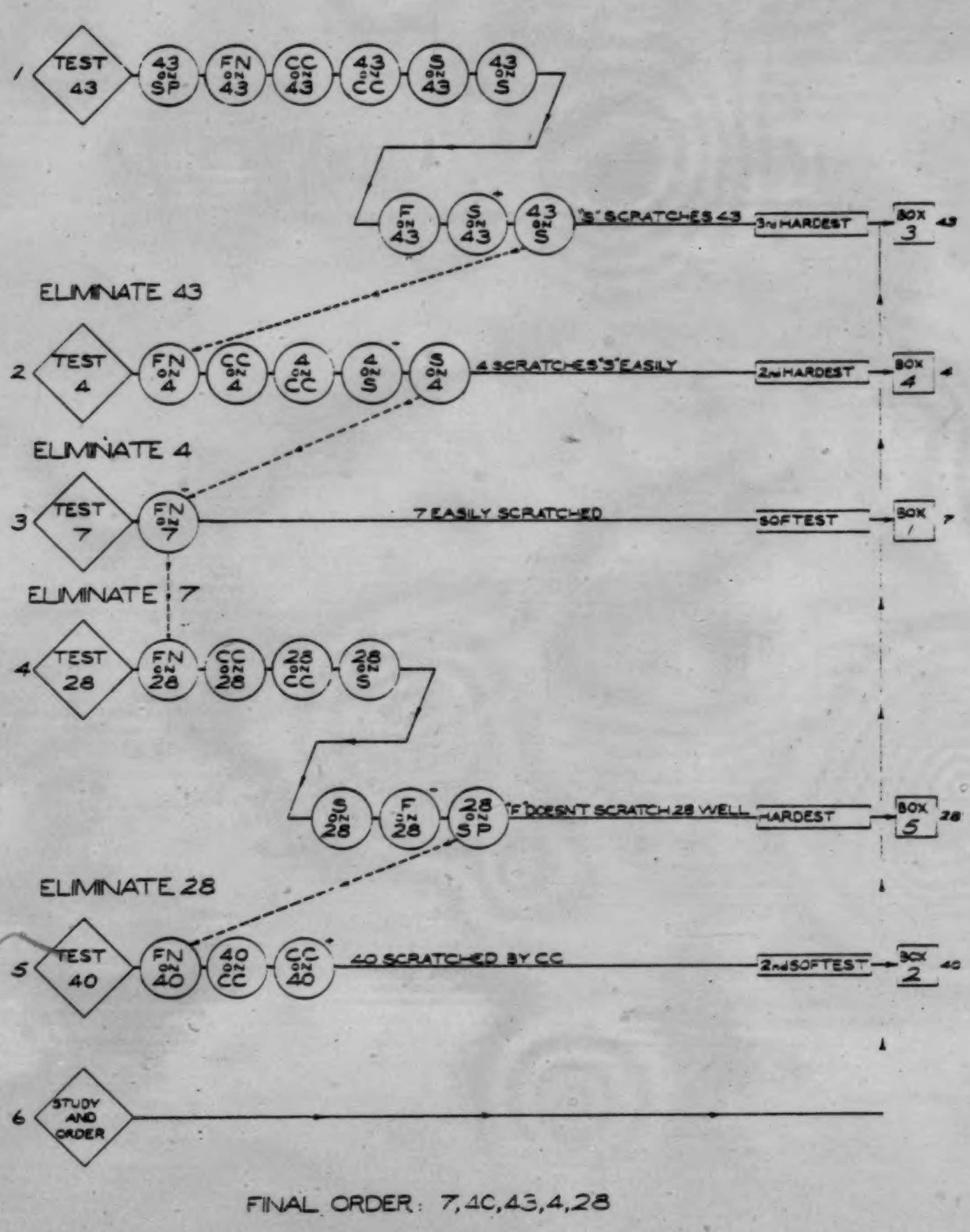

1
TEST 43
43 ON SP
FN ON 43
CC ON 43
43 ON CC
S ON 43
43 ON S
F ON 43
S ON 43
43 ON S
"S" SCRATCHES 43
3rd HARDEST
BOX 3
43
ELIMINATE 43
2
TEST 4
FN ON 4
CC ON 4
4 ON CC
4 ON S
S ON 4
4 SCRATCHES "S" EASILY
2nd HARDEST
BOX 4
4
ELIMINATE 4
3
TEST 7
FN ON 7
7 EASILY SCRATCHED
SOFTEST
BOX 1
7
ELIMINATE 7
4
TEST 28
FN ON 28
CC ON 28
28 ON CC
28 ON S
S ON 28
F ON 28
28 ON SP
"F" DOESN'T SCRATCH 28 WELL
HARDEST
BOX 5
28
ELIMINATE 28
5
TEST 40
FN ON 40
40 ON CC
CC ON 40
40 SCRATCHED BY CC
2nd SOFTEST
BOX 2
40
6
STUDY AND ORDER
FINAL ORDER: 7,40,43,4,28

Figure 11. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Nan.

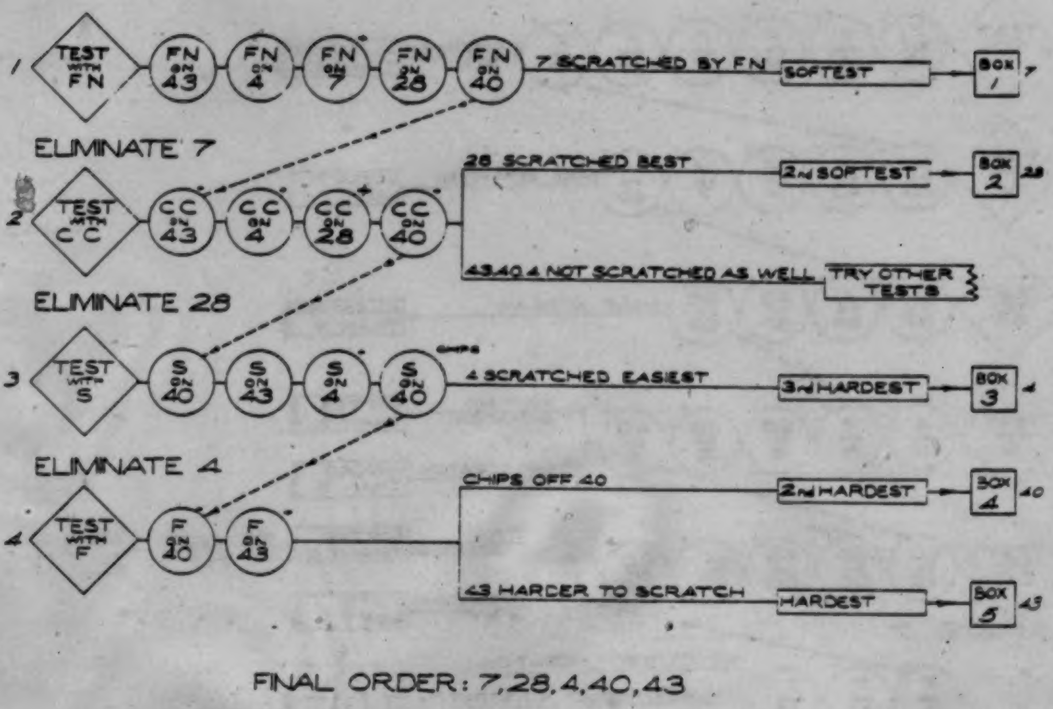

1
TEST WITH FN
FN ON 43
FN ON 4
FN ON 7
FN ON 28
FN ON 40
7 SCRATCHED BY FN
SOFTEST
BOX 1
7
ELIMINATE 7
2
TEST WITH CC
CC ON 43
CC ON 4
CC ON 28
CC ON 40
28 SCRATCHED BEST
2nd SOFTEST
BOX 2
28
43,40,4 NOT SCRATCHED AS WELL
TRY OTHER TESTS
ELIMINATE 28
3
TEST WITH S
S ON 40
S ON 43
S ON 4
S ON 40
CHIPS
4 SCRATCHED EASIEST
3rd HARDEST
BOX 3
4
ELIMINATE 4
4
TEST WITH F
F ON 40
F ON 43
CHIPS OFF 40
2nd HARDEST
BOX 4
40
43 HARDER TO SCRATCH
HARDEST
BOX 5
43
FINAL ORDER: 7,28,4,40,43

Figure 12. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Penny.

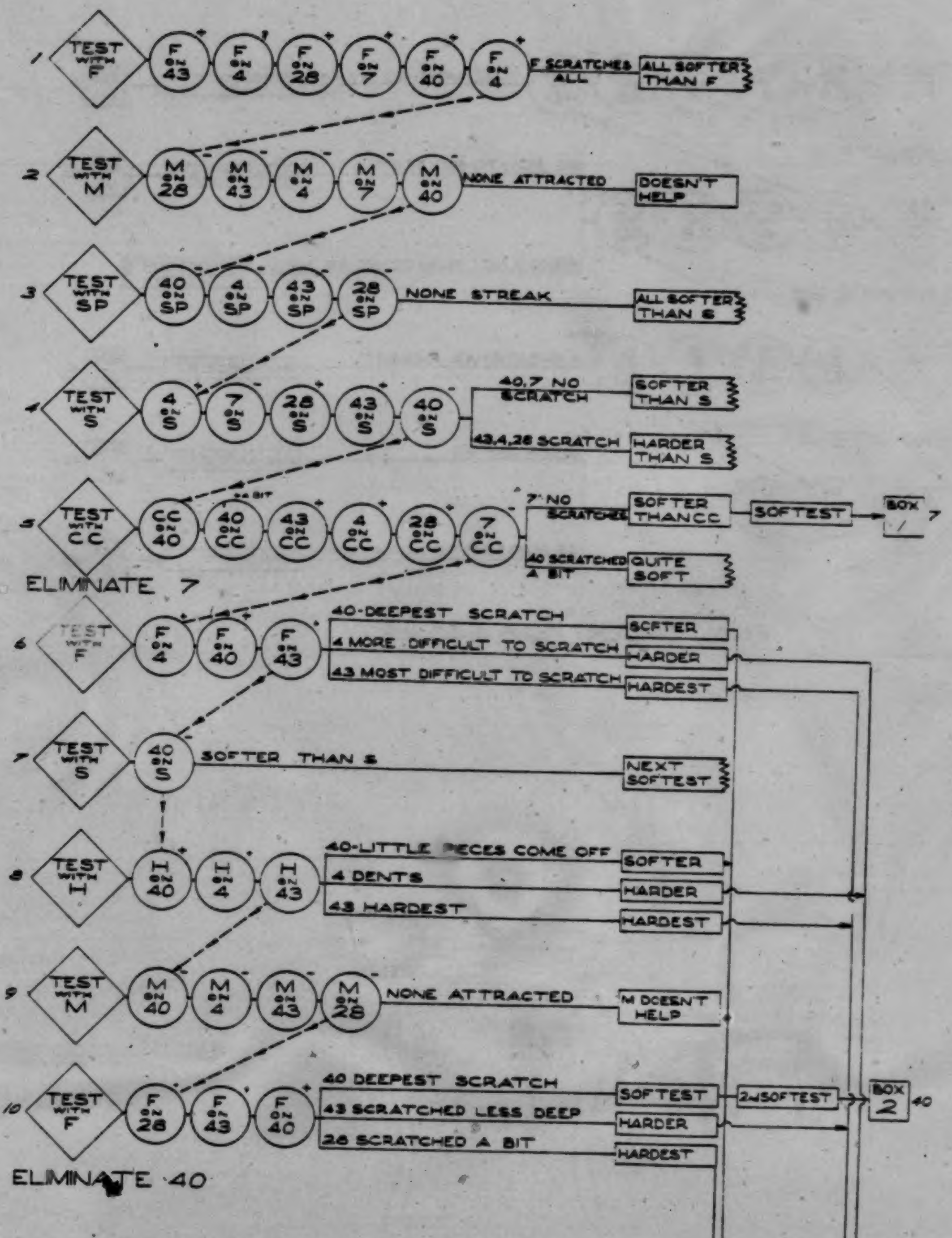

1
TEST WITH F
F ON 43
F ON 4
F ON 28
F ON 7
F ON 40
F ON 4
F SCRATCHES ALL
ALL SOFTER THAN F
2
TEST WITH M
M ON 28
M ON 43
M ON 4
M ON 7
M ON 40
NONE ATTRACTED
DOESN'T HELP
3
TEST WITH SP
40 ON SP
4 ON SP
43 ON SP
28 ON SP
NONE STREAK
ALL SOFTER THAN S
4
TEST WITH S
4 ON S
7 ON S
28 ON S
43 ON S
40 ON S
40,7 NO SCRATCH
SOFTER THAN S
43,4,28 SCRATCH
HARDER THAN S
5
TEST WITH CC
CC ON 40
40 ON CC
A BIT
43 ON CC
4 ON CC
28 ON CC
7 ON CC
7 NO SCRATCHES
SOFTER THANCC
SOFTEST
BOX 1
7
40 SCRATCHED A BIT
QUITE SOFT
ELIMINATE 7
6
TEST WITH F
F ON 4
F ON 40
F ON 43
40-DEEPEST SCRATCH
SOFTER
4 MORE DIFFICULT TO SCRATCH
HARDER
43 MOST DIFFICULT TO SCRATCH
HARDEST
7
TEST WITH S
40 ON S
SOFTER THAN S
NEXT SOFTEST
8
TEST WITH H
H ON 40
H ON 4
H ON 43
40-LITTLE PIECES COME OFF
SOFTER
4 DENTS
HARDER
43 HARDEST
HARDEST
9
TEST WITH M
M ON 40
M ON 4
M ON 43
M ON 28
NONE ATTRACTED
M DOESN'T HELP
10
TEST WITH F
F ON 28
F ON 43
F ON 40
40 DEEPEST SCRATCH
SOFTEST
2nd SOFTEST
BOX 2
40
43 SCRATCHED LESS DEEP
HARDER
28 SCRATCHED A BIT
HARDEST
ELIMINATE 40

Figure 13. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Bill.

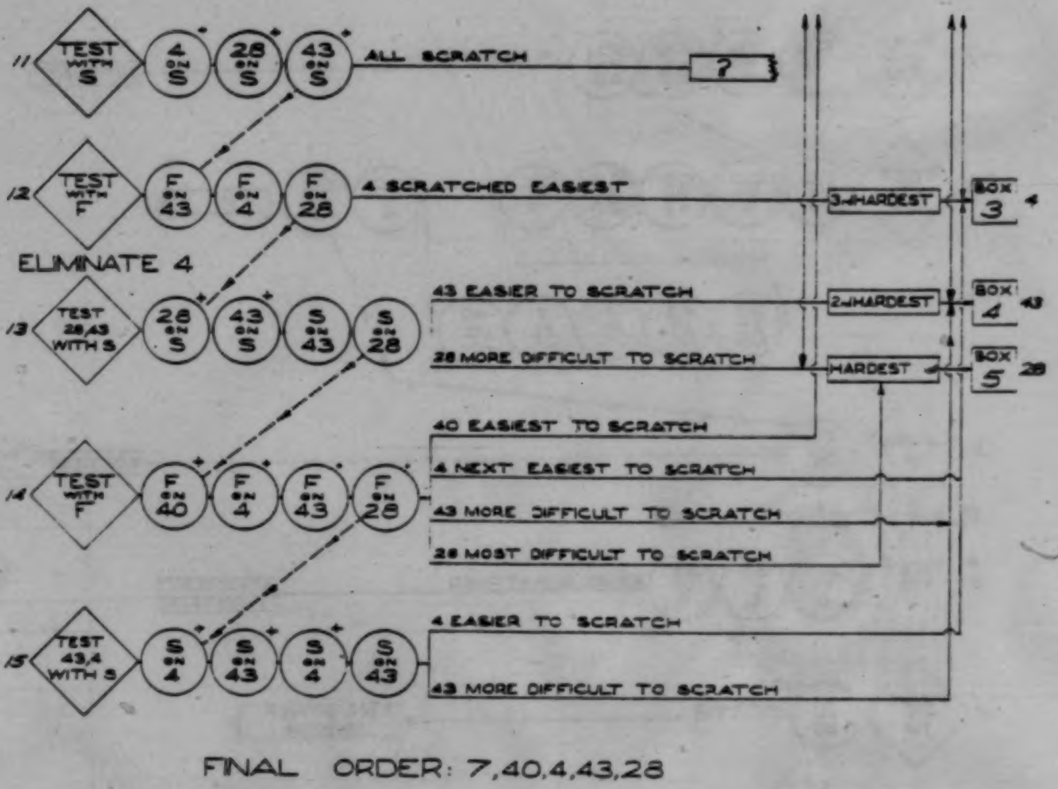

11
TEST WITH S
4 ON S
28 ON S
43 ON S
ALL SCRATCH
?
12
TEST WITH F
F ON 43
F ON 4
F ON 28
4 SCRATCHED EASIEST
3-HARDEST
BOX 3
4
ELIMINATE 4
13
TEST 28,43 WITH S
28 ON S
43 ON S
S ON 43
S ON 28
43 EASIER TO SCRATCH
2-HARDEST
BOX 4
43
28 MORE DIFFICULT TO SCRATCH
HARDEST
BOX 5
28
40 EASIEST TO SCRATCH
4 NEXT EASIEST TO SCRATCH
14
TEST WITH F
F ON 40
F ON 4
F ON 43
F ON 28
43 MORE DIFFICULT TO SCRATCH
28 MOST DIFFICULT TO SCRATCH
15
TEST 43,4 WITH S
S ON 4
S ON 43
S ON 4
S ON 43
4 EASIER TO SCRATCH
43 MORE DIFFICULT TO SCRATCH
FINAL ORDER: 7,40,4,43,28

Figure 13. Continued

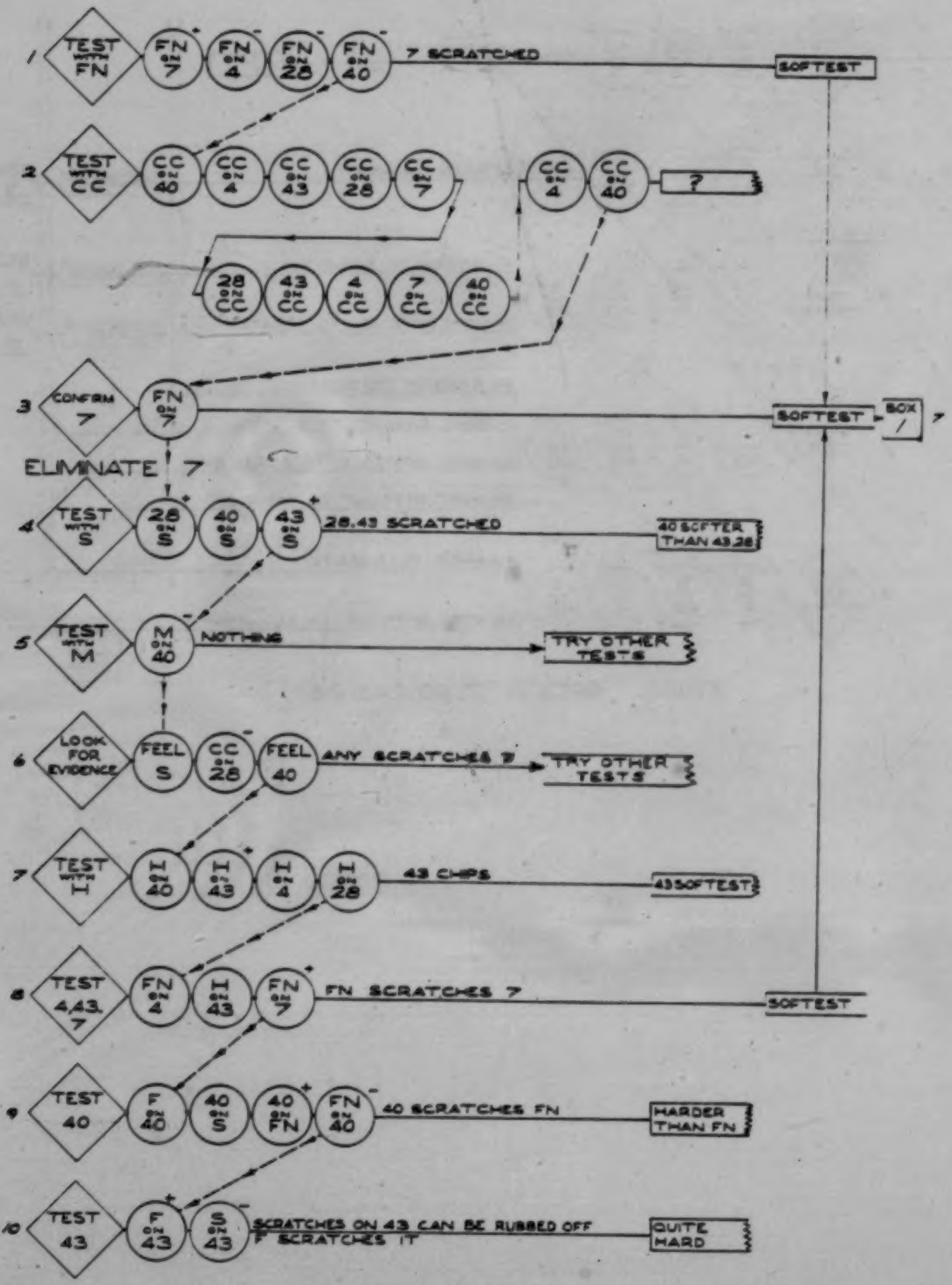

1 TEST WITH FN
FN ON 7 +
FN ON 4 −
FN ON 28 −
FN ON 40 −
7 SCRATCHED
SOFTEST
2 TEST WITH CC
CC ON 40
CC ON 4
CC ON 43
CC ON 28
CC ON 7
28 ON CC
43 ON CC
4 ON CC
7 ON CC
40 ON CC
CC ON 4
CC ON 40
?
3 CONFIRM 7
FN ON 7
SOFTEST
BOX /
7
ELIMINATE 7
4 TEST WITH S
28 ON S +
40 ON S
43 ON S +
28.43 SCRATCHED
40 SOFTER THAN 43.28
5 TEST WITH M
M ON 40 −
NOTHING
TRY OTHER TESTS
6 LOOK FOR EVIDENCE
FEEL S
CC ON 28 −
FEEL 40
ANY SCRATCHES ?
TRY OTHER TESTS
7 TEST WITH H
H ON 40
H ON 43 +
H ON 4
H ON 28
43 CHIPS
43 SOFTEST
8 TEST 4,43, 7
FN ON 4
H ON 43
FN ON 7 +
FN SCRATCHES 7
SOFTEST
9 TEST 40
F ON 40
40 ON S
40 ON FN +
FN ON 40 −
40 SCRATCHES FN
HARDER THAN FN
10 TEST 43
F ON 43 +
S ON 43 −
SCRATCHES ON 43 CAN BE RUBBED OFF
F SCRATCHES IT
QUITE HARD

Figure 14. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Gerry.

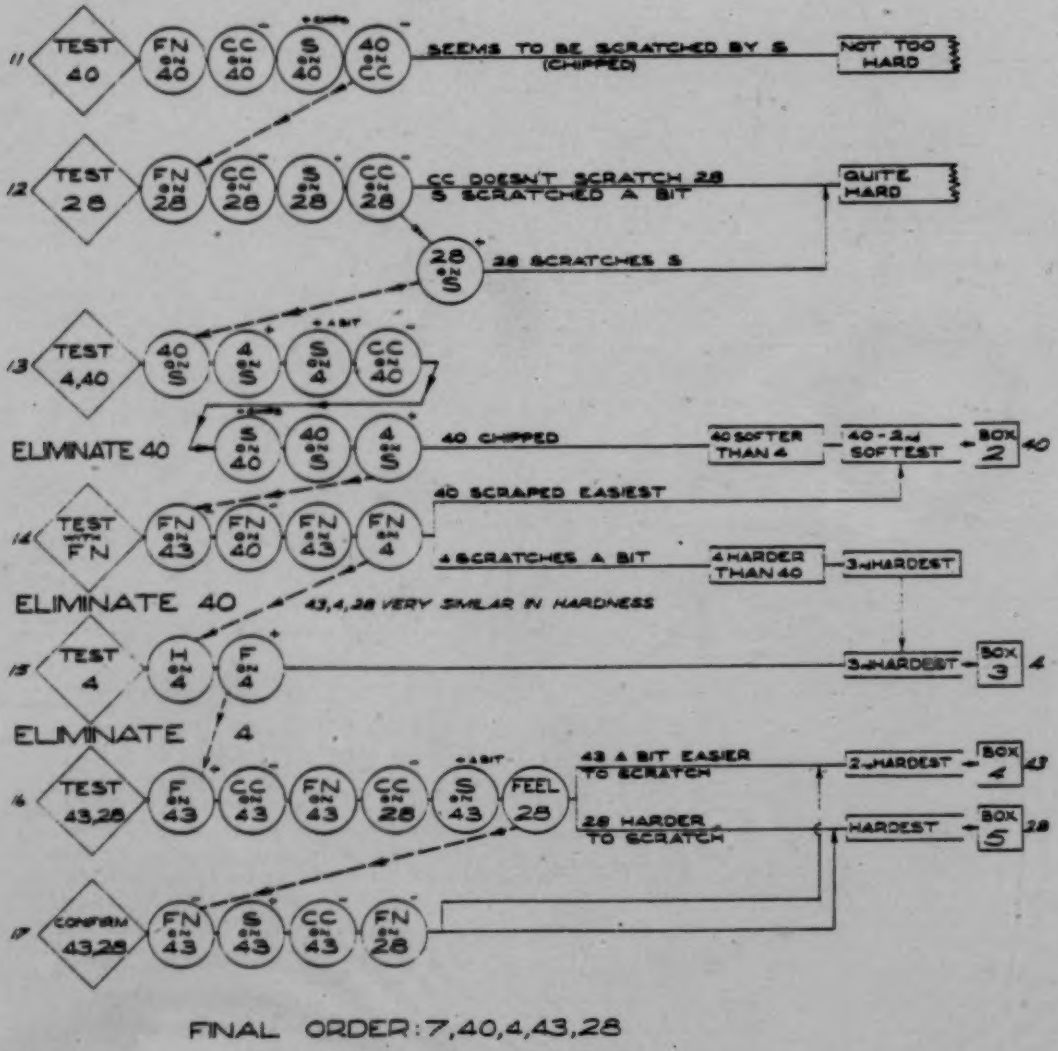

11
TEST 40
FN ON 40
CC ON 40
S ON 40
40 ON CC
SEEMS TO BE SCRATCHED BY S (CHIPPED)
NOT TOO HARD
12
TEST 28
FN ON 28
CC ON 28
S ON 28
CC ON 28
CC DOESN'T SCRATCH 28
S SCRATCHED A BIT
QUITE HARD
28 ON S
28 SCRATCHES S
13
TEST 4,40
40 ON S
4 ON S
+ A BIT
S ON 4
CC ON 40
ELIMINATE 40
S ON 40
40 ON S
4 ON S
40 CHIPPED
40 SOFTER THAN 4
40 - 2nd SOFTEST
BOX 2
40
14
TEST WITH FN
FN ON 43
FN ON 40
FN ON 43
FN ON 4
40 SCRAPED EASIEST
4 SCRATCHES A BIT
4 HARDER THAN 40
3rd HARDEST
ELIMINATE 40
43,4,28 VERY SIMILAR IN HARDNESS
15
TEST 4
H ON 4
F ON 4
3rd HARDEST
BOX 3
4
ELIMINATE 4
16
TEST 43,28
F ON 43
CC ON 43
FN ON 43
CC ON 28
+ A BIT
S ON 43
FEEL 28
43 A BIT EASIER TO SCRATCH
2nd HARDEST
BOX 4
43
28 HARDER TO SCRATCH
HARDEST
BOX 5
28
17
CONFIRM 43,28
FN ON 43
S ON 43
CC ON 43
FN ON 28
FINAL ORDER: 7,40,4,43,28

Figure 14. Continued

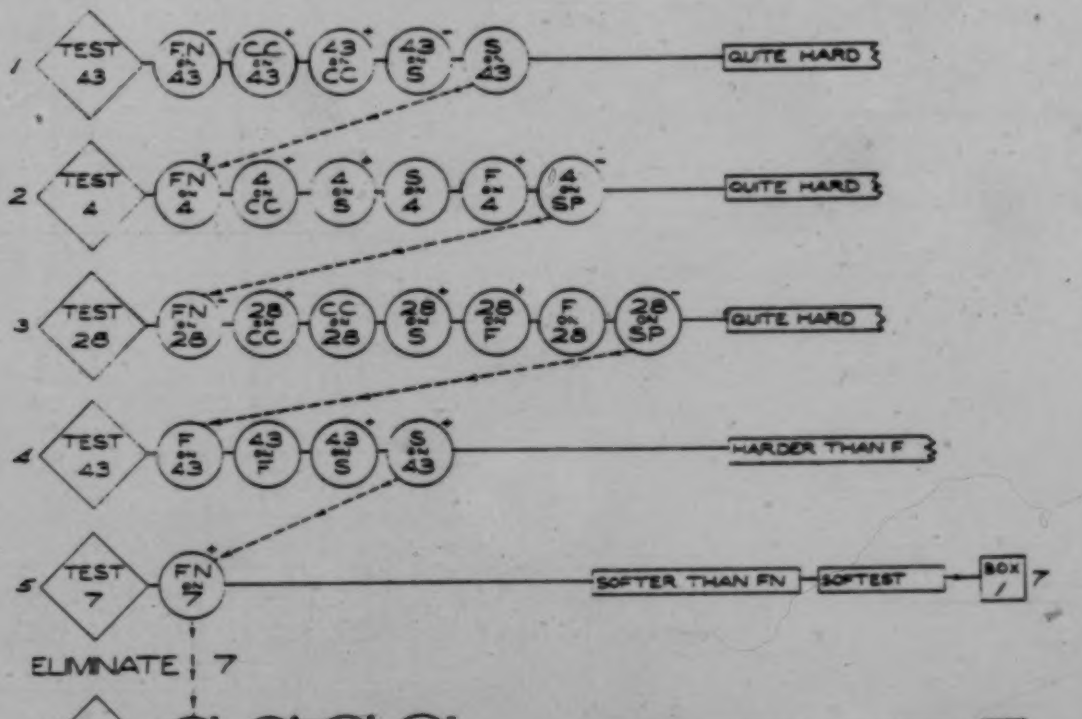

1 TEST 43
FN on 43
CC on 43
43 on CC
43 on S
S on 43
QUITE HARD
2 TEST 4
FN on 4
4 on CC
4 on S
S on 4
F on 4
4 on SP
QUITE HARD
3 TEST 28
FN on 28
28 on CC
CC on 28
28 on S
28 on F
F on 28
28 on SP
QUITE HARD
4 TEST 43
F on 43
43 on F
43 on S
S on 43
HARDER THAN F
5 TEST 7
FN on 7
SOFTER THAN FN
SOFTEST
BOX 1
7
ELIMINATE 7
6 TEST 40
FN on 40
40 on FN
CC on 40
40 on CC
BETWEEN FN & CC
2nd SOFTEST
BOX 2
40
ELIMINATE 40
7 COMPARE 43,4
43 on SP
43 on F
4 on F
FN on 4
NOT SURE
TRY H
8 TEST 43,4 WITH H
H on 43
FN on 43
H on 4
H on 43
43 CHIPS
EASIEST TO BREAK
3rd HARDEST
BOX 3
43
ELIMINATE 43
9 COMPARE 4,28 WITH H
H on 28
H on 4
4 EASIER TO BREAK THAN 28
BREAKS 2nd EASIEST
2nd HARDEST
BOX 4
4
28 HARDEST TO BREAK
HARD TO BREAK
HARDEST
BOX 5
28
FINAL ORDER: 7,40,43,4,28

Figure 15. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Mike.

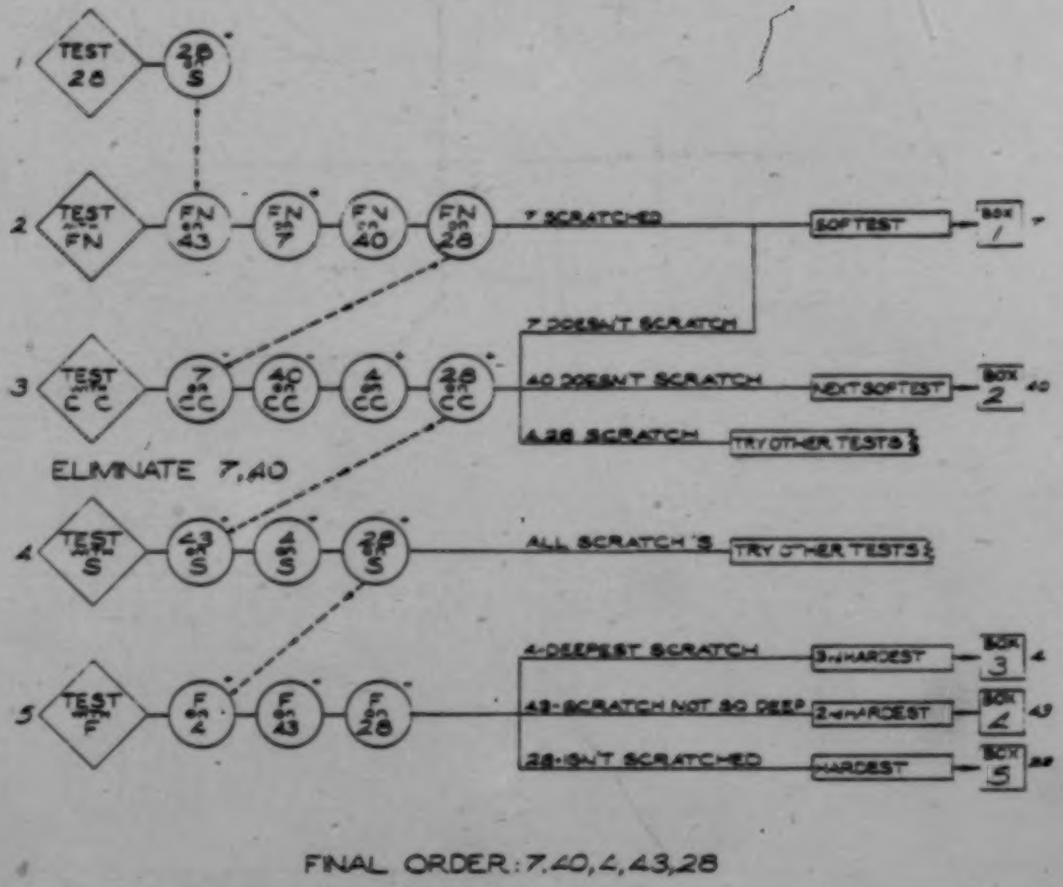

1
TEST 28
28 on S
2
TEST with FN
FN on 43
FN on 7
FN on 40
FN on 28
7 SCRATCHED
SOFTEST
BOX 1
7
3
TEST with C C
7 on CC
40 on CC
4 on CC
28 on CC
7 DOESN'T SCRATCH
40 DOESN'T SCRATCH
NEXT SOFTEST
BOX 2
40
4,28 SCRATCH
TRY OTHER TESTS
ELIMINATE 7,40
4
TEST with S
43 on S
4 on S
28 on S
ALL SCRATCH'S
TRY OTHER TESTS
5
TEST with F
F on 4
F on 43
F on 28
4-DEEPEST SCRATCH
3rd HARDEST
BOX 3
4
43-SCRATCH NOT SO DEEP
2nd HARDEST
BOX 4
43
28-ISN'T SCRATCHED
HARDEST
BOX 5
28
FINAL ORDER: 7,40,4,43,28

Figure 16. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Reid.

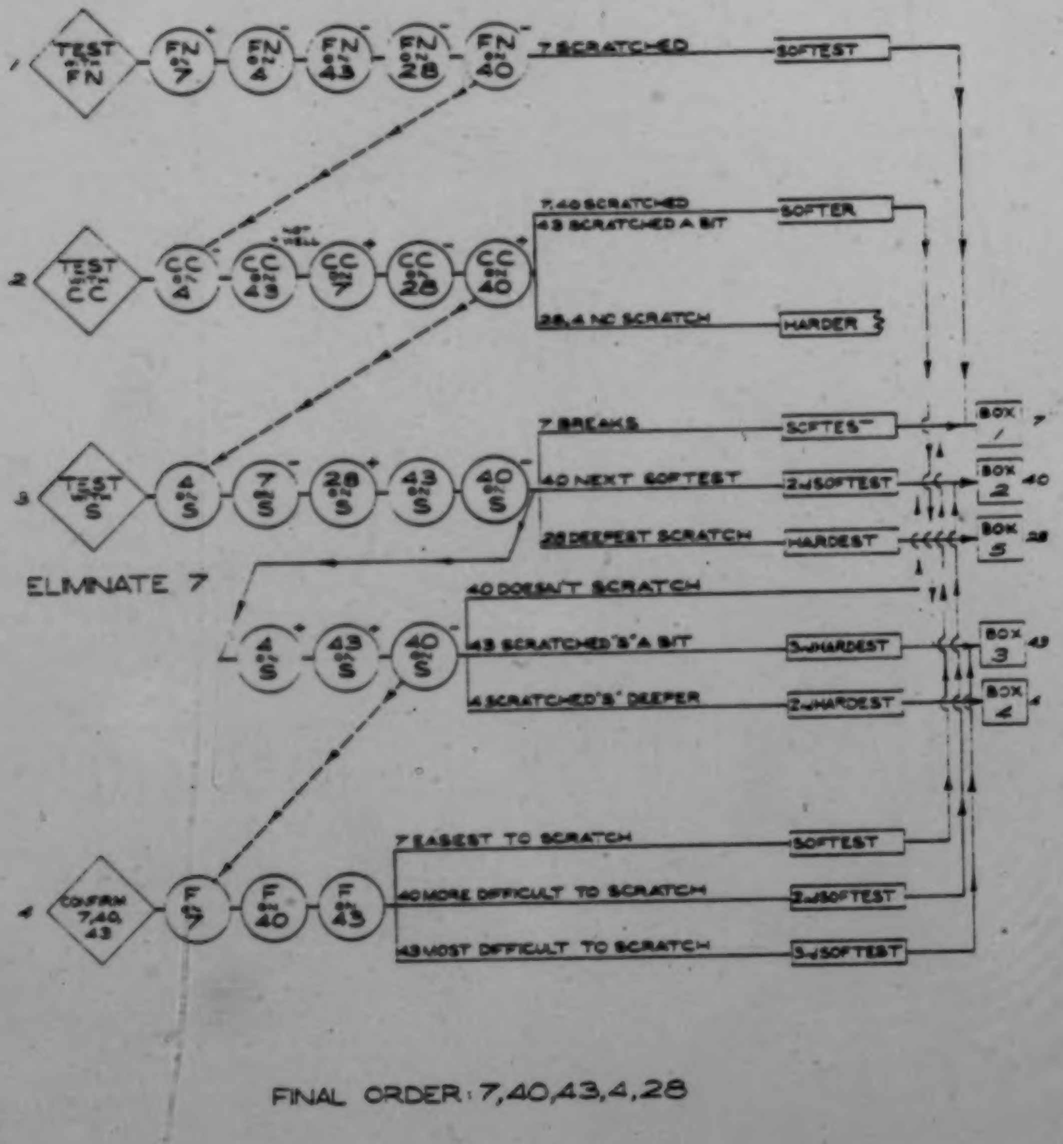

1
TEST WITH FN
FN ON 7
FN ON 4
FN ON 43
FN ON 28
FN ON 40
7 SCRATCHED
SOFTEST
2
TEST WITH CC
CC ON 4
CC ON 43
NOT WELL
CC ON 7
CC ON 28
CC ON 40
7,40 SCRATCHED
43 SCRATCHED A BIT
SOFTER
28,4 NO SCRATCH
HARDER
3
TEST WITH S
4 ON S
7 ON S
28 ON S
43 ON S
40 ON S
7 BREAKS
SOFTEST
40 NEXT SOFTEST
2nd SOFTEST
28 DEEPEST SCRATCH
HARDEST
ELIMINATE 7
4 ON S
43 ON S
40 ON S
40 DOESN'T SCRATCH
43 SCRATCHED 'S' A BIT
3rd HARDEST
4 SCRATCHED 'S' DEEPER
2nd HARDEST
BOX 1
7
BOX 2
40
BOX 5
28
BOX 3
43
BOX 4
4
4
CONFIRM 7,40, 43
F ON 7
F ON 40
F ON 43
7 EASIEST TO SCRATCH
SOFTEST
40 MORE DIFFICULT TO SCRATCH
2nd SOFTEST
43 MOST DIFFICULT TO SCRATCH
3rd SOFTEST
FINAL ORDER: 7,40,43,4,28

Figure 17. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Candy.

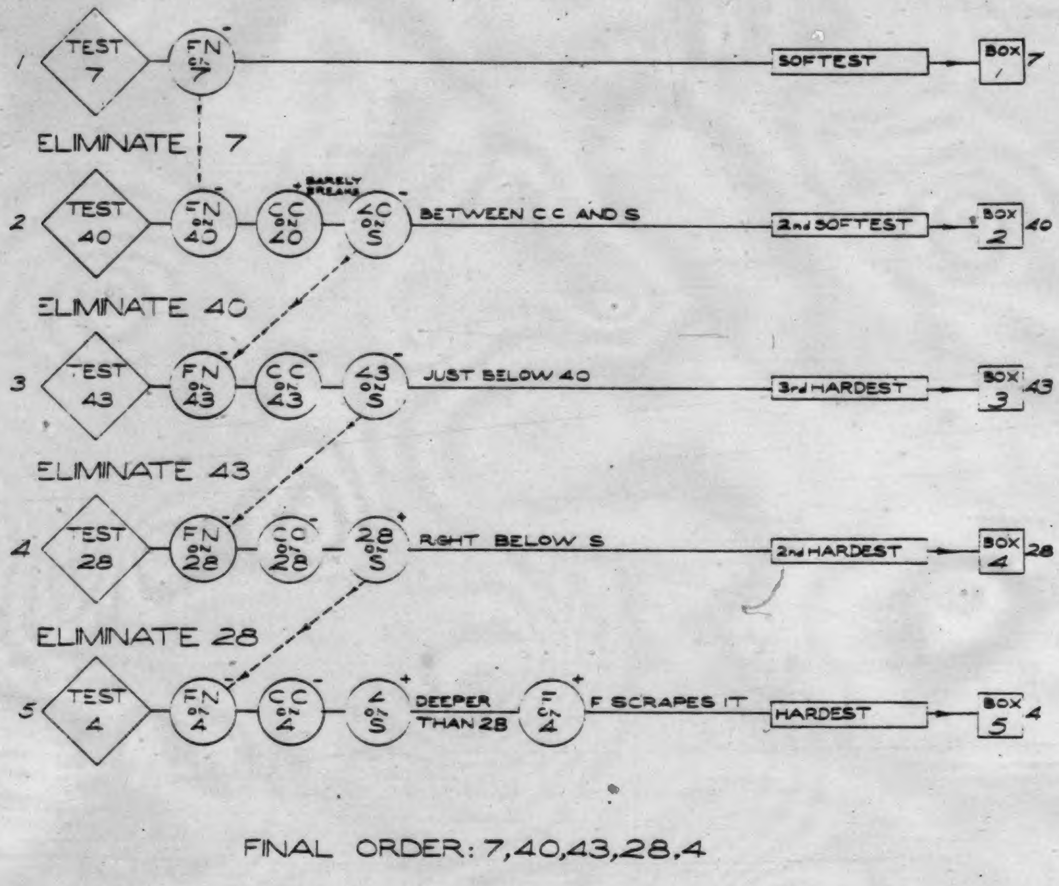

1
TEST 7
FN ON 7
SOFTEST
BOX 1
7
ELIMINATE 7
2
TEST 40
FN ON 40
CC ON 40
BARELY BREAKS
40 ON S
BETWEEN C C AND S
2nd SOFTEST
BOX 2
40
ELIMINATE 40
3
TEST 43
FN ON 43
CC ON 43
43 ON S
JUST BELOW 40
3rd HARDEST
BOX 3
43
ELIMINATE 43
4
TEST 28
FN ON 28
CC ON 28
28 ON S
RGHT BELOW S
2nd HARDEST
BOX 4
28
ELIMINATE 28
5
TEST 4
FN ON 4
CC ON 4
4 ON S
DEEPER THAN 28
F ON 4
F SCRAPES IT
HARDEST
BOX 5
4
FINAL ORDER: 7,40,43,28.4

Figure 18. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Dan.

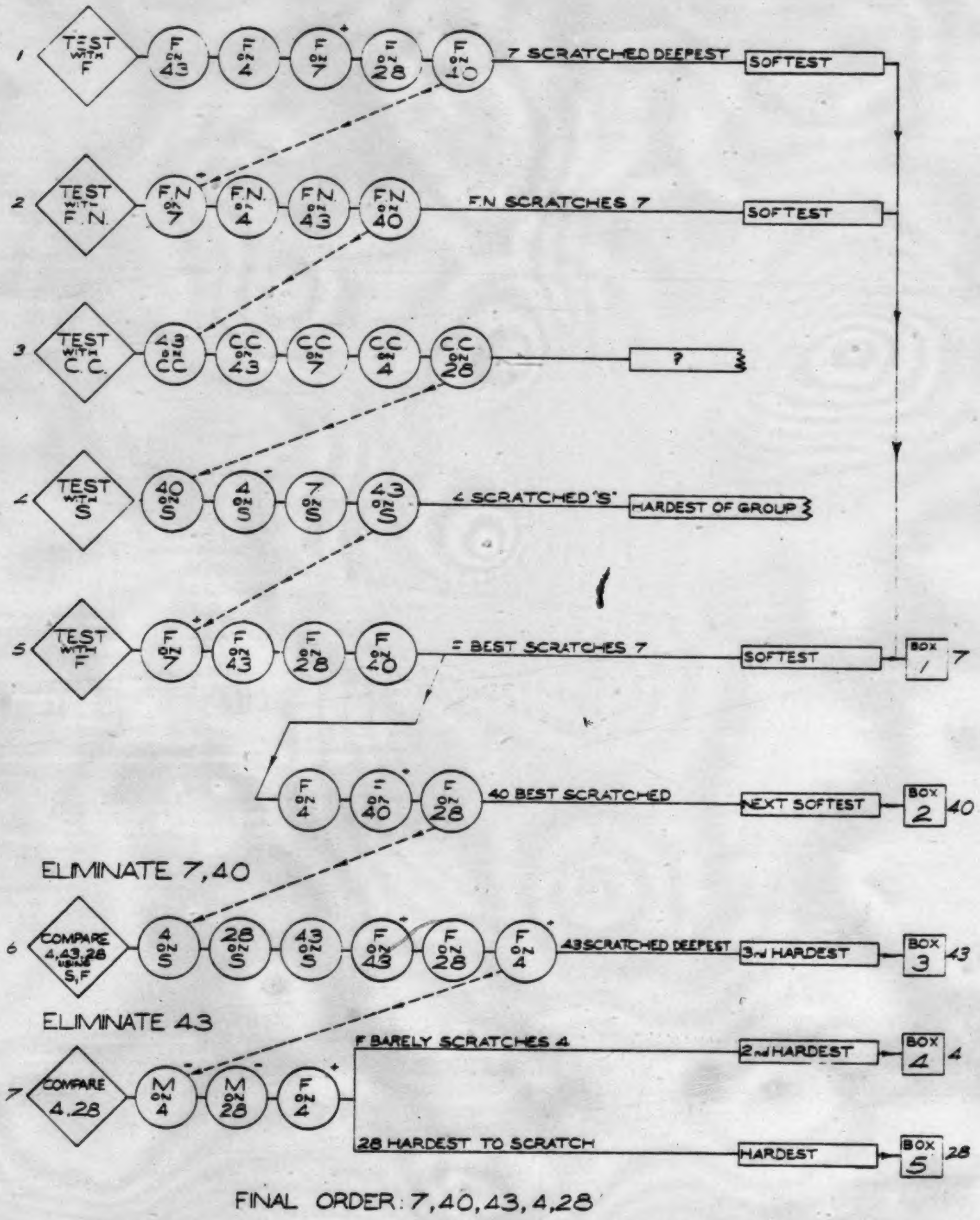

1
TEST WITH F
F ON 43
F ON 4
F ON 7
F ON 28
F ON 40
7 SCRATCHED DEEPEST
SOFTEST
2
TEST WITH F.N.
F.N. ON 7
F.N. ON 4
F.N. ON 43
F.N. ON 40
F.N SCRATCHES 7
SOFTEST
3
TEST WITH C.C.
43 ON CC
C.C. ON 43
CC ON 7
CC ON 4
C.C. ON 28
?
4
TEST WITH S
40 ON S
4 ON S
7 ON S
43 ON S
4 SCRATCHED 'S'
HARDEST OF GROUP
5
TEST WITH F
F ON 7
F ON 43
F ON 28
F ON 40
F BEST SCRATCHES 7
SOFTEST
BOX 1
7
F ON 4
F ON 40
F ON 28
40 BEST SCRATCHED
NEXT SOFTEST
BOX 2
40
ELIMINATE 7,40
6
COMPARE 4,43,28 USING S,F
4 ON S
28 ON S
43 ON S
F ON 43
F ON 28
F ON 4
43 SCRATCHED DEEPEST
3rd HARDEST
BOX 3
43
ELIMINATE 43
7
COMPARE 4.28
M ON 4
M ON 28
F ON 4
F BARELY SCRATCHES 4
2nd HARDEST
BOX 4
4
28 HARDEST TO SCRATCH
HARDEST
BOX 5
28
FINAL ORDER: 7,40,43,4,28

Figure 19. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Laurie.

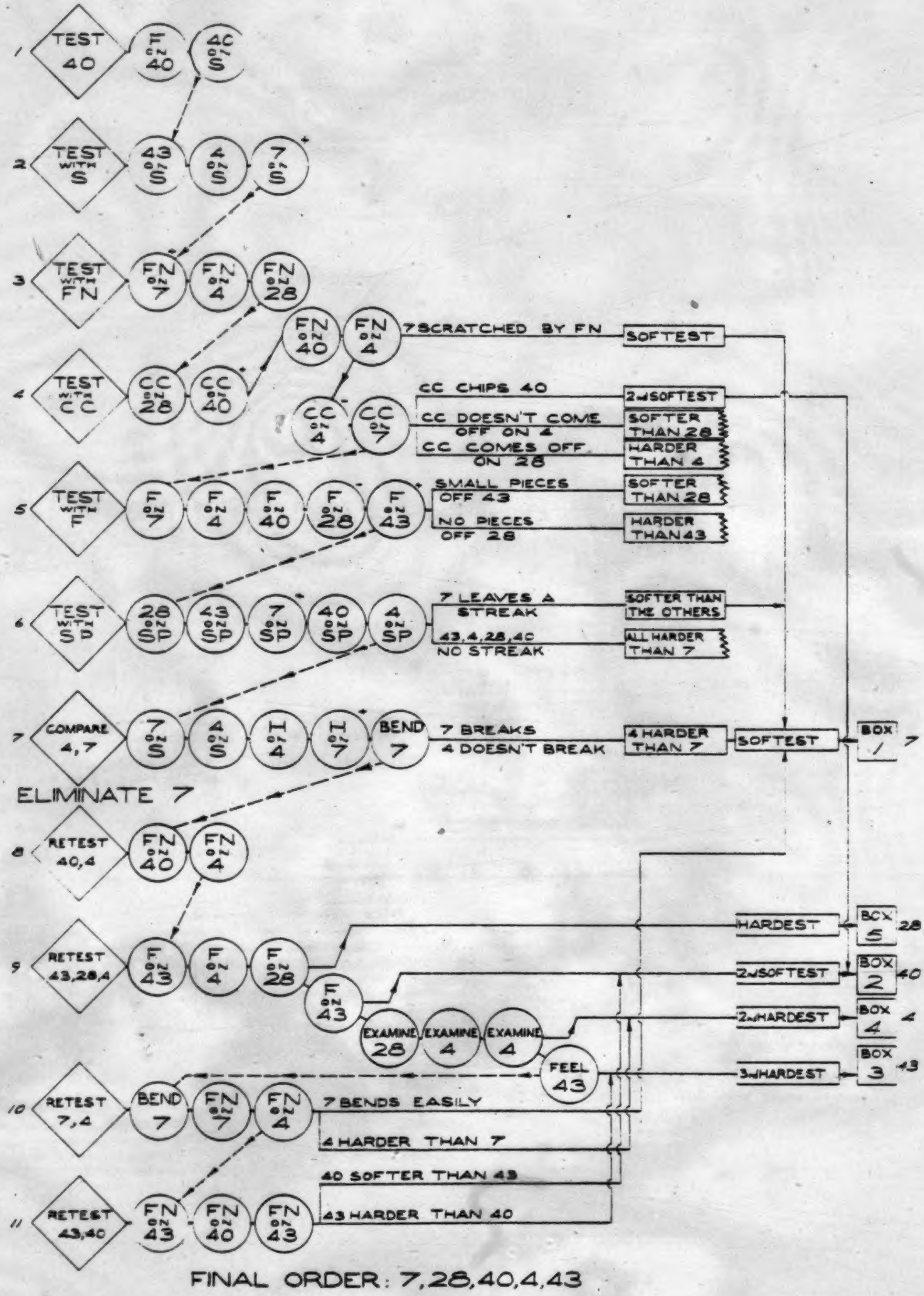

1 TEST 40
F ON 40
40 ON S
2 TEST WITH S
43 ON S
4 ON S
7 ON S
3 TEST WITH FN
FN ON 7
FN ON 4
FN ON 28
4 TEST WITH CC
CC ON 28
CC ON 40
FN ON 40
FN ON 4
CC ON 4
CC ON 7
7 SCRATCHED BY FN
SOFTEST
CC CHIPS 40
2nd SOFTEST
CC DOESN'T COME OFF ON 4
SOFTER THAN 28
CC COMES OFF ON 28
HARDER THAN 4
5 TEST WITH F
F ON 7
F ON 4
F ON 40
F ON 28
F ON 43
SMALL PIECES OFF 43
SOFTER THAN 28
NO PIECES OFF 28
HARDER THAN 43
6 TEST WITH SP
28 ON SP
43 ON SP
7 ON SP
40 ON SP
4 ON SP
7 LEAVES A STREAK
SOFTER THAN THE OTHERS
43,4,28,40 NO STREAK
ALL HARDER THAN 7
7 COMPARE 4,7
7 ON S
4 ON S
H ON 4
H ON 7
BEND 7
7 BREAKS
4 DOESN'T BREAK
4 HARDER THAN 7
SOFTEST
BOX 1
7
ELIMINATE 7
8 RETEST 40,4
FN ON 40
FN ON 4
9 RETEST 43,28,4
F ON 43
F ON 4
F ON 28
F ON 43
EXAMINE 28
EXAMINE 4
EXAMINE 4
FEEL 43
HARDEST
BOX 5
28
2nd SOFTEST
BOX 2
40
2nd HARDEST
BOX 4
4
3rd HARDEST
BOX 3
43
10 RETEST 7,4
BEND 7
FN ON 7
FN ON 4
7 BENDS EASILY
4 HARDER THAN 7
40 SOFTER THAN 43
11 RETEST 43,40
FN ON 43
FN ON 40
FN ON 43
43 HARDER THAN 40
FINAL ORDER: 7,28,40,4,43

Figure 20. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Marlene.

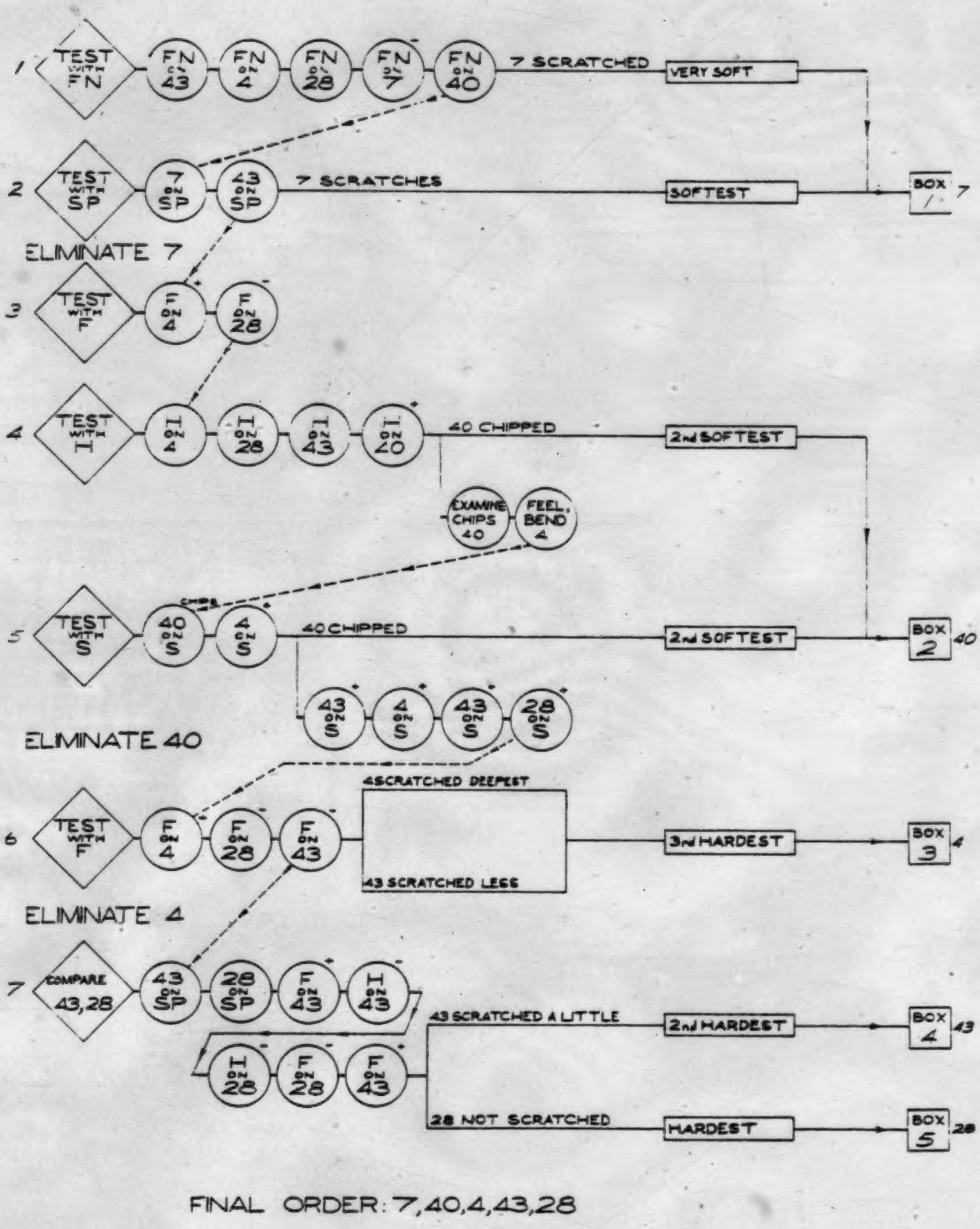

1
TEST WITH FN
FN ON 43
FN ON 4
FN ON 28
FN ON 7
FN ON 40
7 SCRATCHED
VERY SOFT
2
TEST WITH SP
7 ON SP
43 ON SP
7 SCRATCHES
SOFTEST
BOX 1
7
ELIMINATE 7
3
TEST WITH F
F ON 4
F ON 28
4
TEST WITH H
H ON 4
H ON 28
H ON 43
H ON 40
40 CHIPPED
2nd SOFTEST
EXAMINE CHIPS 40
FEEL, BEND 4
5
TEST WITH S
CHIPS
40 ON S
4 ON S
40 CHIPPED
2nd SOFTEST
BOX 2
40
43 ON S
4 ON S
43 ON S
28 ON S
ELIMINATE 40
6
TEST WITH F
F ON 4
F ON 28
F ON 43
4 SCRATCHED DEEPEST
43 SCRATCHED LESS
3rd HARDEST
BOX 3
4
ELIMINATE 4
7
COMPARE 43,28
43 ON SP
28 ON SP
F ON 43
H ON 43
H ON 28
F ON 28
F ON 43
43 SCRATCHED A LITTLE
2nd HARDEST
BOX 4
43
28 NOT SCRATCHED
HARDEST
BOX 5
28
FINAL ORDER: 7,40,4,43,28

Figure 21. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Tommy.

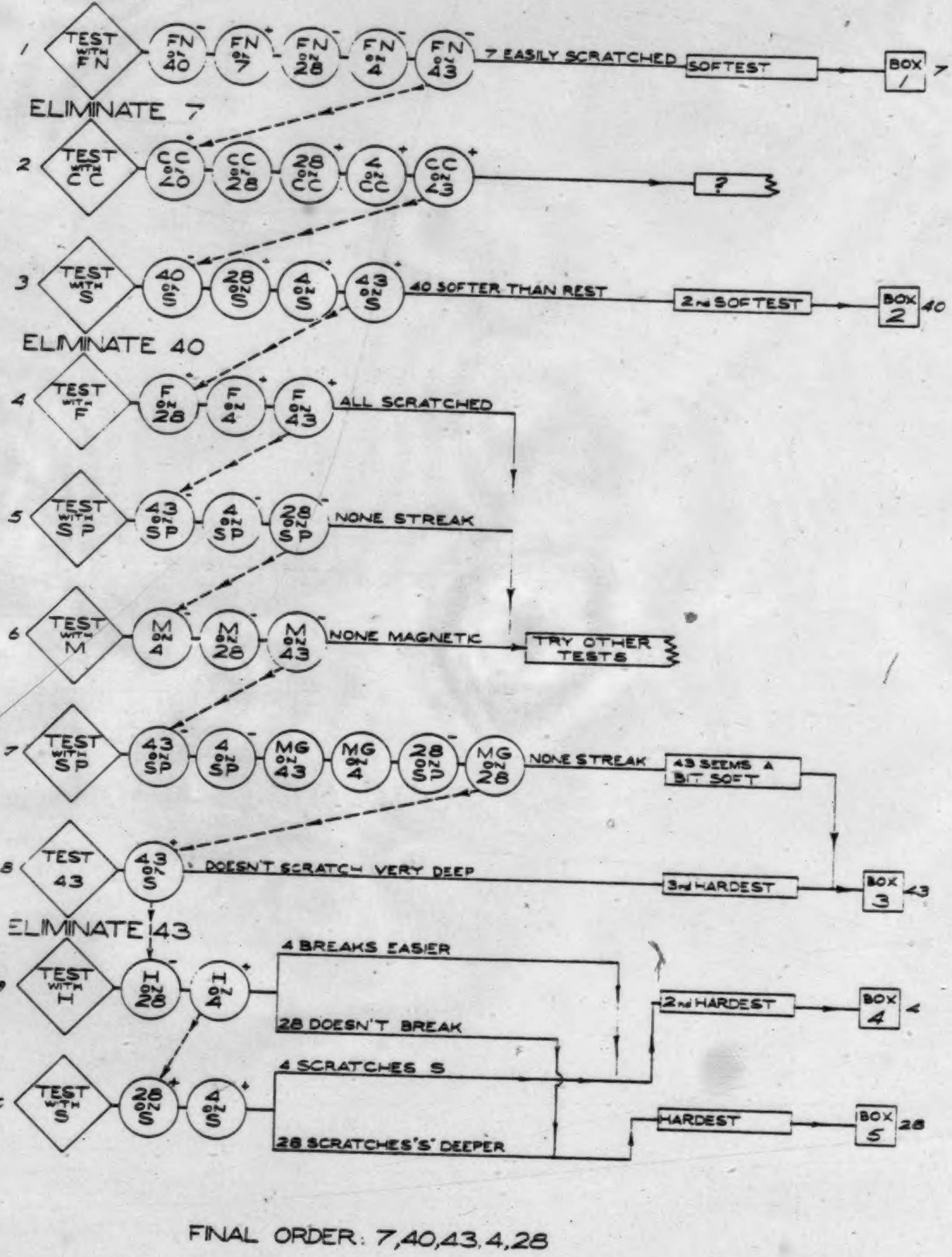

1 TEST WITH FN
FN ON 40
FN ON 7
FN ON 28
FN ON 4
FN ON 43
7 EASILY SCRATCHED
SOFTEST
BOX 1
7
ELIMINATE 7
2 TEST WITH CC
CC ON 40
CC ON 28
28 ON CC
4 ON CC
CC ON 43
?
3 TEST WITH S
40 ON S
28 ON S
4 ON S
43 ON S
40 SOFTER THAN REST
2nd SOFTEST
BOX 2
40
ELIMINATE 40
4 TEST WITH F
F ON 28
F ON 4
F ON 43
ALL SCRATCHED
5 TEST WITH SP
43 ON SP
4 ON SP
28 ON SP
NONE STREAK
6 TEST WITH M
M ON 4
M ON 28
M ON 43
NONE MAGNETIC
TRY OTHER TESTS
7 TEST WITH SP
43 ON SP
4 ON SP
MG ON 43
MG ON 4
28 ON SP
MG ON 28
NONE STREAK
43 SEEMS A BIT SOFT
8 TEST 43
43 ON S
DOESN'T SCRATCH VERY DEEP
3rd HARDEST
BOX 3
43
ELIMINATE 43
9 TEST WITH H
H ON 28
H ON 4
4 BREAKS EASIER
28 DOESN'T BREAK
2nd HARDEST
BOX 4
4
10 TEST WITH S
28 ON S
4 ON S
4 SCRATCHES S
28 SCRATCHES 'S' DEEPER
HARDEST
BOX 5
28
FINAL ORDER: 7,40,43,4,28

Figure 22. Strategy for determining the order of hardness of selected minerals (softest to hardest) according to Wanda.

the inferences and conclusions arrived at by the child were determined on the basis of close examination and integration of both verbal and operational behaviour as displayed on video tape and from data derived from the discussion between child and participant observer which followed, all of these kinds of manifestation of behaviour being of vital importance in contributing to an overall and thorough understanding of the actual strategies employed by the child. For example, the strategy used by Penny in determining the order of hardness of the five minerals, Talc, Halite, Fluorite, Apatite and Corundum (see Figure 12) can be described as follows:

> Penny began by applying a specific test (fingernail test) to each mineral in turn. She began by scratching mineral 43 (Fluorite) with the fingernail (FN on 43) next scratching mineral 4 (Apatite) with the fingernail (FN on 4) and so on until all minerals had been tested. Penny observed that mineral 7 (Talc) was scratched by the fingernail, a positive test result (+), and inferred that it was the softest mineral. She then recorded the number of mineral (7) in the first Box (Box 1), set Talc aside, and proceeded to test the remaining minerals. Following the hardness scale, she next tested minerals 43, 4, 28 and 40 (Stage 2, Test with CC), scratching each in turn with a copper coin (CC on 43, CC on 4, CC on 28 and CC on 40). Penny observed a positive test result for all tests but noted that mineral 28 "scratched the best" (indicated by the large plus (+) sign), inferred that 28 was the second softest mineral, and recorded that number in Box 2. Then, mineral 28 was set aside and the remaining three minerals were tested, in turn, using the piece of steel and the file until the final order of hardness (7, 28, 4, 43, 40) was obtained.

Examination of such operational behaviours of all the children (see Figures 6 to 22) revealed that each child employed some definite and definable operational strategy in performing the set task, although some strategies appeared to embody a more systematic structure and style than others. In general children followed the order of testing as suggested by the defined hardness scale which had been presented to them, usually beginning with the fingernail test, following through with the copper coin, steel and the file. In contrast to the suggestions embodied in the intended strategy, children usually did not terminate a particular test once a positive result had been obtained. Instead, they tended to continue on with the same test as if to 'check out' their results or to gather more information as a basis for further decision making. Two principal strategies emerged, however, from all of this, both involving the use of the hardness scale apparently on either a 'deliberate' or 'intuitive' basis.

Principal Strategies

The first general strategy used by the majority (70%) of the children involved the selection of a testing implement from the suggested group and using it to test each mineral in turn (see Figures 6, 8, 9, 12, 13, 14, 16, 17, 19, 20, 21 and 22). In contrast with the intended strategy, each subsequent test did not result in a yes or no decision but usually led, instead, to a series of tests before a decision was reached on the hardness of a specific mineral. Upon completion of a particular sequence of testing, another implement was selected and the same procedure repeated until the hardness of each mineral had been determined to the student's satisfaction. Sometimes, as the hardness of a particular mineral was determined to the satisfaction of the child, it was eliminated from the ensuing testing sequences. However, most children were seen to continue testing given minerals even though at least one positive test for that mineral had been observed. This procedure represented a not uncommon but major deviation on the part of the children from the intended strategy.

The second general strategy, one which closely resembled the intended strategy, and which was used by 30% of the children (see Figures 7, 10, 11, 15 and 18), involved selecting a mineral and testing it with some or all of the given devices, this process usually being continued until a positive test resulted. Nan's strategy typified this approach (see Figure 11). Nan began by testing mineral 43 (Fluorite, H-4) on the streak plate, a test which she did not use again, and then against the fingernail, copper coin, piece of steel and the file. Since the steel scratched the Fluorite, she tentatively decided that Fluorite was the third softest mineral. Mineral 4 (Apatite, H-5) was then tested in a similar manner and its hardness tentatively assessed as being second in rank. The fingernail test identified Talc as the softest mineral so no further tests were carried out upon that mineral. Mineral 28 (Corundum, H-9) required testing through the sequence up to use of the file which "didn't scratch it very well", the conclusion then being reached that Corundum was the hardest mineral. Mineral 40 (Halite, H-2) was scratched by the copper coin which led it to be labelled as the second softest mineral. Nan's final determination of the order of hardness 7, 40, 43, 4, 28, was correct. It should be noted that although Nan primarily applied the scratch/no scratch criterion, she also noted other phenomena such as ease of scratching, a factor which contributed to her decision making process. The four other children who used this strategy followed similar procedures (see Figures 7, 10, 15, 18). Although children occasionally were observed to apply facets of both strategies to their determinations they nonetheless tended to manifest one modus operandi.

Examination of the flow charts also revealed the extent to which children relied upon additional information such as ease of scratching, depth of scratch, and amount of force, for example, in helping them make decisions about the hardness of minerals. This substantiated the observation that application of a scratching technique as an external operation did not necessarily mean the child was applying the scratching criterion in internal processing of data acquired.

Children's Success at Applying the Various Testing Techniques

Tables 9 and 10 summarize the major findings derived from the tally of individual flow charts (see Appendix I, Tables A-R). Table 9 provides a summary of the testing techniques and the information children said they used to assist them in ordering the minerals (see Appendix I, Tables B-R) while Table 10 provides a tally of the tests which children actually were observed to apply during the mineral ordering activity (see Appendix I, Table A). This combination of what children did and said provided me with the basis for identifying strategies and procedures used by the children when ordering a given set of minerals.

Table 10 indicates that Talc (H-1), the softest mineral, was observed by the children to be scratched by all of the devices provided, the majority (76%) noting that the fingernail scratched Talc, this factor being used as the primary test in identifying it

Table 9

Percent of Children Reporting Use or Non-Relevance of Testing Techniques in Determining Hardness of Selected Minerals

Test/Evidence	Scratching Technique					Breaking Technique						Other Techniques		
	fingernail test	copper coin test	steel plate test	file test	streak plate test	Number of pieces	Size of pieces	Ease of chipping	Ease of bending	Amount of force required	Hammer useful	Depth of scratch	Attracts magnet	Others
Actually Used	76%	94%	100%	100%	35%	59%	41%	65%	59%	82%	59%	59%	35%	n.m.
Not Relevant	n.m.	n.m.	n.m.	n.m.	18%	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	35%	35%

Note. n.m. = not mentioned

N = 17

Table 10

Percent of Children Observed to Employ Various Testing Techniques

Minerals softest to hardest	Scratching Techniques									Breaking Techniques							Other Techniques
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral "marks" Streak Plate	Number of Pieces	Size of Pieces	Ease of Chipping	Ease of Bending	Amount of Force Required	Hammer Useful	Depth of Scratch	Attracts Magnet
#7 Talc H-1	76%	6%	12%	n.o.	12%	n.o.	24%	n.o.	41%	n.o.	n.o.	n.o.	24%	6%	12%	n.o.	12%
#40 Halite H-2	6%	12%	53%	6%	24%	6%	35%	6%	n.o.	n.o.	n.o.	6%	6%	6%	24%	n.o.	24%
#43 Fluorite H-5	n.o.	n.o.	29%	18%	29%	65%	82%	6%	12%	n.o.	n.o.	n.o.	6%	6%	18%	6%	18%
#4 Apatite H-6	n.o.	n.o.	12%	29%	24%	88%	82%	n.o.	6%	n.o.	n.o.	n.o.	6%	n.o.	29%	n.o.	24%
#28 Corundum H-9	n.o.	n.o.	18%	35%	6%	76%	24%	6%	n.o.	n.o.	n.o.	n.o.	6%	n.o.	6%	n.o.	24%

Note. n.o. = not observed

N = 17

as the softest mineral. It should be noted, however, that 40% of the children also observed that Talc left a streak on the streak plate, a breaking test that was not essential as far as the determination of the hardness of Talc was concerned. The degree to which this information contributed to the final conclusions reached by the child was not determinable; however, the application of the scratching criterion, to the neglect, from their point of view, of other possible supporting sources of data.

Halite (H-2), the second softest mineral may be scratched by the copper coin and its hardness determined in that way. Halite, of course, will, therefore, be amenable to scratching by the piece of steel or the file, both considerably harder than copper. While only just over half of the children were actually observed to record the production of a scratch when using the copper coin on Halite, over 90% nevertheless claimed that they used the test in determining the hardness of Halite. Furthermore, several children mentioned that they also relied upon additional evidence such as depth of scratch, ease of scratching or chipping in their determinations indicating that criteria other than the scratch criterion alone were being applied. This became particularly evident in those cases in which children identified the hardness of Halite by using the piece of steel or the file which also, of course, produced a positive scratch test result with several other minerals.

No child was observed to report a positive fingernail test for the remaining minerals — Fluorite (H-4, Apatite (H-5), or Corundum (H-9) the differences in hardnesses between these minerals and the fingernail perhaps being so large as to preclude inaccuracies in observation and reporting. The hardness determination with respect to Fluorite appeared, in most cases, to be determined primarily on the basis of the results obtained by the use of the piece of steel or the file. Eighty-two percent of the children accurately observed that the file (H-6½ to 8) scratched the Fluorite (H-4), however, 65% also reported that the Fluorite scratched the piece of steel (H-5½). This discrepancy could be accounted for by several factors, not only those such as the variations in 'character' encountered in the mineral specimen and in the hardness variations possible with the steel, but also by the testing techniques employed by the children several of whom were observed to be applying considerable force in order to obtain a scratch. It should be noted that the amount of force to be applied when attempting to scratch a mineral is not specified in Mohs scale, nor by the curriculum developers. No class discussion regarding this factor was held although several children were observed to remark that they "had to apply the same amount of pressure" each time they applied a scratch test. 'Scratches' vs 'scratched by' in effect is a feature of this test which differs from that employed on the Mohs scale. Several children also used the hammer as a decision making tool concerning the hardness of the Fluorite. The five children who noted that the coin scratched the Fluorite probably misinterpreted the significance of the copper streak left behind on the mineral, a common error associated with the scratch test being the confusion arising between the production of an actual scratch on the mineral being tested and a streak left on the mineral by a testing device which is softer in fact than the mineral.

Although Apatite (H-5) is close to Fluorite (H-4) in hardness, more children (88%) did in fact note that it scratched the piece of steel rather ("better"?) than did the Fluorite (65%), the majority (82%) also noting that the file scratched both minerals. Again, children were observed to use evidence such as ease of scratching and also depth of scratch to determine the hardness of the Apatite. The majority of the children also seemed to use the steel test in determining the hardness of the hardest mineral Corundum (H-9) often indicating that it scratched 'better' and 'deeper' than did the other minerals. Several children inaccurately reported that the copper coin and the file scratched the Corundum when they concluded that the streak left behind by the instrument was a scratch on the mineral, evidence again of confusion between the scratcher and the scratchee.

Although few of the children were actually observed applying the breaking criterion such as using the hammer as Table 10 indicates, Table 9 reveals that children were, in fact, relying on evidence other than scratch/no scratch in making inferences about mineral hardness. More than half of the children used evidence associated with the breaking criterion such as the number of pieces breaking off a mineral, ease of chipping and bending, and particularly important from their point of view, the amount of force needed to scratch chip or break a mineral. Although only 59% of the children said they actually used the hammer to help determine the hardness of some of the minerals, the remaining 41% said that the hammer could be used to determine mineral hardness even though they had elected not to use it in this particular way. This suggested that it might be anticipated that all of the children could be expected to use the hammer as an instrument for testing for hardness at some time or another, particularly when all else had failed.

Table 9 further reveals that not all children concurred with the implementation of certain tests for determining mineral hardness, namely the streak plate test and the magnet test. Although 35% of the children said the magnet test was useful in determining hardness of minerals, an equal number disagreed, correctly noting that magnetism had nothing to do with hardness of minerals.

As the glass plate used in conjunction with the hardness scale in the Minerals and Rocks unit was not available for the culminating activity, some children initially appeared to substitute the streak plate for it. After several streaking attempts, however, most children seemed to realize that the streak plate was not of much use although some of them appeared to use the streaking action of Talc as evidence of the softness of that mineral. One child, Laurie, used the streak plate to 'listen' for a scratch, an observation which yielded evidence which she said was useful in helping her to differentiate between the hardnesses of some minerals.

Comparison and Summary of Intended and Actual Strategies

As already noted 30% of the children applied a general strategy similar to that specified as the intended strategy, the majority, however, applying quite a different general strategy which centered around selecting a testing implement and applying it to each mineral in turn. Although these alternate strategies resembled the intended strategy and generally required fewer steps for their completion such approaches did not necessarily allow the children to achieve greater accuracy in their final determinations.

A major deviation from the intended strategy on the part of all children consisted of decisions to use additional evidence in determining the hardness of minerals, such as ease of scratching, depth of scratch and amount of force required to produce a scratch. Although the children used such evidence to a greater or lesser extent, such lines of investigation nevertheless constituted an integral part of the method of determining mineral hardness. In contrast with the suggestions embodied in the intended strategy, children did not rank the scratching criterion above all other criteria but used it, rather, in conjunction with other criteria, particularly the breaking criterion. In general children were seen to secure results from the various hardness tests that were in line with the 'correct' results, a factor which suggests that, regardless of strategy and implementation of predetermined criteria, they were still able to complete the task reasonably well and accurately especially when the limitations placed on them by the difficulties inherent in the materials is taken fully into account.

Use and Effectiveness of Evidence Other than the Scratching Criterion in the Differentiation of Mineral Hardness

Many of the children were observed to use evidence other than the scratching criterion to help them distinguish between minerals of varying hardnesses. Accordingly, an examination of the basis of decision making with regard to this other evidence seemed appropriate. Table 11 illustrates how children who focused on the

Table 11

Children's Responses
Indicating Number of Pieces
Broken off Selected Minerals

Minerals softest to hardest	Number of Pieces				
	Many	A lot	Some	Few	None
#7 Talc H-1	M C c				
#40 Halite H-2		P t M C c			
#43 Fluorite H-5			P t M		
#4 Apatite H-6				t c W	D C
#28 Corundum H-9				C	P t M W

Note. c=Candy; C=Chuck; D=Dan; M=Marlene; P=Penny; t=Tim; W=Wanda.

number of pieces breaking off a mineral as an indication of hardness categorized this information. As the children were observed to use terms such as "many", "a lot", "some", "few" and "none" when describing the number of pieces that broke off minerals following scratching or chipping, these terms seemed to be the most appropriate to incorporate in the table as a basis for the categories (informal criteria) for identifying minerals of differing hardness. The pattern of responses given by the children indicates a system of logic which appeared to operate on the principle that the greater number of pieces breaking off, the softer the mineral and the fewer the number of pieces breaking off, the harder the mineral. Because of the possibility of error inherent in the implementation of this method of determining hardnesses of minerals, some inaccuracies could be anticipated particularly when attempts are made to distinguish between minerals which are close in hardness, such as Fluorite and Apatite. This approximate method of determining mineral hardness did in fact work sufficiently well, however, to enable some children to make fairly accurate estimates of mineral hardness.

A similar situation, illustrated in Table 12, shows how children used 'ease of chipping' to help them differentiate between minerals of different hardness. The general phenomenon operating here was that of softer minerals being more easily scratched than harder minerals. Terms such as "very easily scratched", "easy to scratch", "quite easy to scratch" and so forth were used by some children in describing the magnitude of the force or pressure needed to chip a mineral. Although this method produced some erroneous results, once again between minerals close in hardness, in general

Table 12

Children's Responses
Indicating Ease of Chipping
Using Selected Minerals

Minerals softest to hardest	Ease of Chipping				
	Very Easily	Easy	Quite Easily	Difficult	Most Difficult
#7 Talc H-1	P t D S M B R N C L c				
#40 Halite H-2		t D G T C L			
#43 Fluorite H-5			t P C	M	
#4 Apatite H-6				t M C L W	
#28 Corundum H-9					M t C W

Note. B=Bill; c=Candy; C=Chuck; D=Dan; L=Laurie; M=Marlene; N=Nan; P=Penny; R=Roy; S=Sam; t=Tim; W=Wanda.

such a procedure produced evidence which appeared to be effective in helping to distinguish between minerals of different hardness.

Depth of scratch was another source of evidence used by a number of children in assisting them in their determination of the hardness of minerals. Table 13 shows that children in fact did observe that softer minerals displayed the deepest scratch while the harder minerals displayed minimal scratching. A further illustration of the consistency of this logic as applied by the children can be seen upon examining the reverse of this situation, namely the depth of scratch produced by minerals on the testing implements.

Table 13 also reveals that children observed that the harder minerals produced deeper scratches in testing implements than did the softer minerals. It appeared, therefore, that when children used this testing procedure they did so in a systematic fashion and arrived at logically consistent conclusions. Inconsistencies in observation and determinations emerge once again with respect to Fluorite and Apatite, with Corundum posing some problems for those children estimating the depth of scratch produced in it by particular testing implements.

Tables 11, 12 and 13 suggest that when children used additional evidence such as number of pieces chipping off a mineral, depth of scratch or ease of chipping, they were applying systems of logic that in many cases worked quite effectively. In general, it allowed them to differentiate correctly between minerals differing significantly in hardness, although the in-between minerals often presented difficulties, particularly, as noted, in the case of Fluorite and Apatite which are close in terms of mineral hardness.

Table 13

Children's Responses Indicating Depth of Scratch Using Selected Minerals

Minerals	Depth of Scratch in Minerals				Depth of Scratch in Test Implements			
softest to hardest	Deep Scratch	Some Scratching	Barely Scratches	No Scratch	Deep Scratch	Some Scratching	Barely Scratches	No Scratches
#7 Talc H-1	t D S c							t
#40 Halite H-2		P C R					B L	S M R
#43 Fluorite H-5	R	T R	S C	G D		B L	P c	S R
#4 Apatite H-6	T	G R	P S R	D	L	D S P W	P B	
#28 Corundum H-9		G R	G N D c	P S T C c	P S B R W			

Note. B=Bill; c=Candy; C=Chuck; D=Darla; G=Gerry; L=Laruie; M=Marlene; N=Nan; P=Penny; R=Reid; R=Roy; S=Sam; t=Tim; T=Tommy; W=Wanda.

This latter case constitutes an example of the unreliability when attempts are made to apply criteria other than the scratch/no scratch criterion. The difficulty lies in the inability of the experimentor to control factors such as amount of force applied, or in factors such as the subjectivity of the determination with respect to the ease of chipping or the estimation of the some or many pieces which have chipped off a mineral. Because such determinations are so subjective and difficult to control, reliance upon such evidence can lead to incorrect inferences, a circumstance which the results obtained by the children clearly demonstrated.

Orders of Hardness as Determined by the Children

Table 14 summarizes the orders of hardness as determined by the children for the selected minerals, less than half of them (47%) being able to produce the correct ordering. All of the children succeeded in correctly identifying Talc (H-1) as the softest mineral; 88% accurately identified Halite (H-2) as the second softest mineral and 78% identified Corundum (H-9) as the hardest mineral. The two 'in-between' minerals, Fluorite (H-4) and Apatite (H-5) were ordered correctly by less than half of the children (47% and 41% respectively). Accuracy in identifying the hardness of the minerals at the extreme ends of the hardness scale is perhaps to be expected, but the results obtained may also have been due in part to the characteristics of the mineral specimens provided. The nature of the minerals in the middle range of the hardness scale, those displaying 'average' properties that is, may have contributed to the difficulty in identifying their specific hardnesses, particularly

Table 14

Orders of Hardness of Selected Minerals
As Determined by the Children

Children	Orders of Hardness of Selected Minerals Softest . . . . Hardest[a]				
Chuck	7	4	40	43	28
Roy	7	40	4	43	28
Tim	7	40	43	4	28
Sam	7	40	28	43	4
Candy	7	40	43	4	28
Laurie	7	40	43	4	28
Tommy	7	40	4	43	28
Marlene	7	40	43	4	28
Darla	7	40	4	28	43
Reid	7	40	4	43	28
Wanda	7	40	43	4	28
Bill	7	40	4	43	28
Nan	7	40	43	4	28
Gerry	7	40	4	43	28
Mike	7	40	43	4	28
Penny	7	28	4	40	43
Dan	7	40	43	28	4

[a] Correct Order of Hardness:

#7	#40	#43	#4	#28
Talc	Halite	Fluorite	Apatite	Corundum
H-1	H-2	H-4	H-5	H-9

in view of the doubtful reliability and consistency of the relatively coarse testing devices coupled with the use of criteria other than the scratching criterion.

Summary of Children's Perceptions and Strategies Regarding the Determination of Mineral Hardness

The investigation indicates that the intentions of the curriculum developers for the Minerals and Rocks unit were not realized in that children frequently did not use the materials provided in the manner envisioned nor did they apply concepts and techniques relating to hardness determinations as originally conceived and anticipated.

With respect to these issues the general outcomes of the investigation may be summarized as follows.

1. Children's common-sense understanding of hardness was associated strongly with an experientially based 'breaking' element. Applying a scientific definition of hardness required them to suspend this experiential knowledge and, instead, to associate hardness of minerals with resistance to scratching. Few children were observed to do this consistently.

2. Children did not apply the scratching criterion exclusively, but also used secondary evidence associated with the breaking criterion such as depth of scratch and ease of scratching to help them make decisions about the hardness and consequently the position in the order of hardness of a particular mineral. This seemed to indicate that they had not made a transition from an everyday understanding of hardness

to the scientific understanding of the concept.

3. Although the children initially experienced difficulty in dealing with a hardness scale, they eventually became accustomed to it. During culminating activities all children were observed usually to use the hardness tests in the order suggested by the scale, thus indicating that they had grasped the idea behind the use of the scale, had internalized it and were applying it, even though some children seemed not to be aware that they were doing so.

4. Children and geologists displayed similar procedural techniques such as the application of scratching techniques, feeling for evidence of a scratch, rubbing off after scratching attempts and recording on the hardness table. Differences in the degree of knowledge and experience brought to the tasks, however, were evident with professionals taking into account the relative nature of judgements involved, the imprecisions inherent in the activities, and the condition of the specimens. In addition, they applied exclusively the scratching criterion.

5. Most children did not follow the intended strategy suggested to them for ordering minerals, applying instead variations of the intended strategy, systematic variations which allowed them, nevertheless, to secure ordering of the minerals, although frequently this ordering proved to be incorrect.

6. When given the freedom of choice with respect to whether the scratcher or the scratchee should be used in testing, children were observed to apply both approaches

systematically. The approach and the application employed by most children appeared to be influenced by the shape of the testing device, the copper coin and the piece of steel, for example, being used more often as the scratchee and the fingernail and the file as the scratcher.

Aside from any curriculum problems that may have been associated with the unit, inherent constraints were associated with methods of determining mineral hardness, such constraints being in part associated with the sophistication, experience and finesse required for the correct determination of this particular physical property. Coupled to these factors, the use of relatively coarse measuring devices, the nature of the specific mineral specimens involved, and the requirement that the children accurately determine mineral hardness within a setting which is redolent with an air of subjectivity make the study of this particular property difficult at best.

Chapter VI

CONCLUSIONS AND RECOMMENDATIONS

Overview of the Study

A major intent of this study was the investigation of the viewpoints of children regarding the physical properties of minerals, particularly the property of hardness. Indepth observation of children in the classroom provided the primary vehicle for the identification of relevant areas of inquiry and for the collection of data relating to such inquiry. Although it was not known at the outset what information, if any, about children's belief systems might emerge from the observation of children working according to a prescribed program with minerals and rocks, it seemed reasonable to assume that children working with natural materials in the everyday environment of their classrooms offered the potential of providing a significant source of data.

Soon after the science classes began, it became apparent that considerable amounts of data were emerging, the challenge then becoming one of identifying and focusing primarily upon those data related to the physical properties central to the study. The physical property hardness eventually became evident as constituting one problem area which the children were encountering, this problem subsequently becoming the major focus for the study. During the course of the investigation several related curricular issues surfaced and received attention, such issues being associated with discrepancies between the intent of the curriculum developer, the final perceptions of the children and the particular materials chosen to provide instruction relating to the nature of the physical property of mineral hardness.

As a result of the study several hypotheses may be formulated and discussed regarding the viewpoints of children with respect to hardness of minerals. These propositional statements, which are presented here in the form of conclusions, and the implications of such conclusions will now be discussed, additional comments regarding the applicability of participant observation to the area of concept development in young children also being provided together with recommendations and suggestions for further research.

Conclusions and Implications

The following major conclusions emerged from the study:

1. _Children's understanding of the physical property of hardness of minerals may be regarded as constituting a continuum ranging from a common-sense understanding of the nature of the concept, associated with the notion of breaking, to a formal scientific understanding of the concept, associated with scratching. Breaking, however, constitutes the predominant operational evaluative criterion as far as children are concerned_.

This range of understanding became manifest through the manner in which children talked about and carried out their experimental procedures relating to the determination of mineral hardness. The breaking approach found its expression through those children who, as a matter of course, hit minerals or attempted to bend or to chip them, the hardness of minerals then frequently being described in terms of the ease with which a mineral broke, or in terms of the number and size of the pieces which broke off the mineral specimen. When pressed to suggest additional ways of assessing hardness of minerals, the children mentioned measures such as throwing the minerals on the ground, 'stomping' on them, or using a steam roller to crush them, all such suggestions constituting a reflection of the breaking point of view.

At the conclusion of their study of minerals and rocks only a few of the children appeared to manifest an understanding of the scientific meaning of hardness. It is further to be noted that, even when applying the scratching criterion, most children were seen to be focusing primarily on the depth of the scratch or upon the ease with which the scratching was produced rather than being concerned with whether or not a scratch had been produced.

The majority of the children, however, did not elevate the scratching criterion above other possibilities, electing instead to select a specific criterion or a combination of criteria on the basis of the situation at hand. Although scratching techniques were often used in such instances, the children seemed then to be primarily concerned about the amount of pressure needed to produce a scratch, the ease of bending and chipping also being of concern. The fact that children occasionally used magnets as a means of determining hardness via magnetic properties, and also suggesting additional methods such as heating the mineral or dropping acid on it, further indicated that such children did not understand the true nature of the test and were not operating from a scientific perspective.

By the conclusion of the unit it appeared, therefore, that few children had internalized the meaning of hardness as defined scientifically as had been intended, but confused hardness with the breaking characteristics of the mineral. Several explanations for this may be offered. First, children were being required to suspend their everyday common-sense understanding of hardness which generally was associated with breaking and adopt instead an 'artificial' or scientific meaning for hardness as it relates specifically and technically to minerals, the evaluation on the latter being based solely on an order of scratch production. This transfer of understanding and comprehension evidently did not occur, for the children continued to rely upon the evidence produced by the breaking phenomenon in order to help them determine mineral hardness, thus suggesting that their experiential knowledge had been, and continued to be, a strong influence upon their thinking and in their modus operandi . Their involvement in the several 'process' activities which they were required to use in conjunction with the new concept of hardness apparently was insufficient and inadequate to enable most of the children to make the required leap in understanding.

According to Vygotsky (1962), such an outcome reflects the process by which children acquire scientific concepts in that the new relationship between the development of scientific concepts and everyday concepts is a very dynamic one with children's everyday common-sense concepts and scientific concepts developing in reverse directions. Accordingly, children become conscious of everyday concepts relatively late, their ability to define the everyday concept and operate upon this definition appearing long after their spontaneous acquisition of the concept. Scientific concepts on the other hand, often are introduced through formal verbal definitions, their application then occurring through non-spontaneous operations by working with the concept itself, such concepts, therefore, beginning life in the child's mind at a level acquired only later with respect to everyday concepts.

In the case of the concept of hardness, it soon became apparent that the children's everyday understanding of the concept was saturated with meaning, the association which they commonly established between hardness and breaking having its origins in experiences such as 'bashing' pennies, bending nails, smashing things, and in the accidental breaking of dropped objects. Their subsequent introduction to the scientific concept of hardness with its associated precise meaning as related to minerals had the potential, and did, create confusion, conflicting as it did with a long standing association between hardness and breaking. The confusion might also have been compounded by the fact that children were not presented with a formal definition of the concept of hardness nor were they exposed to any indepth discussion concerning the concept, but were expected, instead, to reach understanding and recognition through application. The fact that most children, after being actively involved in exercises purportedly designed to enable them to acquire the concept, did not come to any understanding calls into question the current practice in education, particularly in science, of avoiding any provision of verbal or written definitions of concepts, the assumption being that children learn more effectively by becoming involved in activities requiring the use of the concept -- the 'process' approach in its extreme form -- the implications of which will be discussed later.

Vygotsky went on to contend that the development of the child's everyday concepts proceeds upward while the development of scientific concepts proceeds in a downward direction to a more concrete level, the two developmental sequences being closely connected, one strongly influencing the other. Accordingly, during development, the everyday concept clears a path for the scientific concept and its development, this in turn, supplying a foundation, together with the formulation of appropriate conclusions, for the development of everyday concepts and their formal comprehension. Thus it would seem that in addition to concentration on the scientific meaning of hardness, attention also needs to be given to addressing the everyday concept of hardness held by the children, this to be coupled with an attempt to influence the desired transition to a true scientific understanding of the concept involved.

The process involved in developing a true understanding of formally defined physical phenomena such as hardness, is continuous, long term and difficult. It is epitomized by the situation which leaves university professors in an ongoing condition of puzzlement with respect to the frequency with which their beginning geology students also associate mineral hardness with breaking, a predicament which regularly and distressingly results in loss of valuable mineral specimens to hammer blows.

Even these chronologically (and intellectually?) more mature students may not have been provided with adequate opportunity to examine critically, or even consciously, their own everyday conception of hardness nor, often, are they able to develop the background knowledge and experience necessary for appropriate application of the scientific concept. It would appear that in many instances involving initial contact with a new concept, people tend to do the same thing, whether they be children or adults, that is, they unconsciously rely upon and apply everyday experiential knowledge, particularly in situations which appear to involve practical common-sense. This situation would appear to have ramifications for other subject areas as well. Does the beginning reader, for example, whether child or adult, experience similar problems? If so, knowledge of strategies in one area might reinforce understanding of the other. In the particular instance under study, knowledge and understanding of the pervasiveness with which children associate hardness with breaking might lead to the anticipation of a similar association with respect to adults thus permitting us to prepare to deal in advance with potential problems at higher instructional levels, the study of elementary school science, thus potentially being of significance for the resolution of problems to be encountered at the university level.

A second conclusion relating to the understanding of the concept of mineral hardness on the part of children which emerged from the study is that:

2. Children tend to operate in relative rather than in absolute terms.

Throughout the course of the investigation no child was observed to apply an exclusively dichotomous approach to the determination of hardness of minerals, particularly the scratch/no scratch dichotomy (which is basic to the formal scientific application of the concept), although several children tended towards this level of understanding. Many children, instead, applied a variety of criteria in order to help them determine mineral hardness although, regardless of the criterion being applied, children usually focused on 'degrees' of evidence (how much, how many, how large) which were manifested by any particular testing technique -- as epitomized by typical remarks such as: "The scratch didn't go as deep"; "This one doesn't need as much pressure as that one"; "I looked at how many chips came off"; "I looked at how big the chips were"; or "I can bend this one real easily". Although a few children appeared to embrace the preferred scientific use of the concept almost exclusively, they too were observed to revert to the use of relative evidence when experiencing difficulty in distinguishing between two minerals of very similar hardness.

Mike, who had applied the primary formal scratching criterion in ordering a set of minerals, illustrates this point in that he was able to determine the hardness of three of the minerals upon application of this criterion, but could not distinguish between the remaining two minerals which happened to be very close in hardness. At this point Mike picked up the hammer, hesitated, and said, "Goodness, hardness -- it's not scratch", and replaced the hammer. After several more scratching attempts he decisively picked up the hammer, hit the remaining minerals and subsequently made a decision regarding their hardness on the basis of ease of breaking.

It might, at this juncture, be argued that it was not the logical thinking of the child which was imperfectly developed, but rather the coarse imprecise nature of the measuring instruments which caused frustration and precipitated the breaking behaviour. Although such an argument could be made, the consistent manner in which children were observed to apply relative criteria such as 'how much' and 'how many' throughout the duration of the unit cannot be ignored, suggesting that children are concerned with evidence of a relative nature, rather than, or as much as, they are concerned with absolute data based on logical deduction from the data at hand, data which is itself derived from a pursuit of formally defined procedures. The manifestation of such examples of operational behaviour carries implications both for curriculum developers and for teachers, each group needing to be aware of this apparently inherent tendency in children. Even assuming that an activity is meritorious in its own right (a point to be discussed later) allowances still need to be made, and activities designed, in such a way that children are helped to move in the desired direction, in this particular case towards application of the scratching criterion in a dichotomous manner as intended, rather than in allowing the activity to unintentionally reinforce the children's preferred (more natural) mode of operation. In other words, the activity should ensure that not only do most of the children reach the desired objective but that the design of the experience to which they are exposed should also ensure that they reach the defined objective by design rather than by chance.

Another related conclusion addressed itself to the manner in which children went about solving the problem of ordering a set of minerals according to hardness:

3. Children apply a systematic strategy in their determination of mineral hardness.

Although few children followed the intended strategy for determining the order of hardness of a given set of minerals precisely, all of them did apply some definable strategy, and one which even allowed them to order the minerals more or less correctly -- this situation emerging somewhat surprising because, on the surface, it had appeared that the children were in general operating in a rather haphazard fashion. The speed with which they worked, coupled with their seemingly uninterrupted flow of action, gave the superficial appearance of operation in a trial and error fashion. Indepth analysis of their approaches to the problem revealed, however, that the children proceeded quite systematically, generally applying one of two strategies. The first strategy, which resembled the original intended strategy, involved selecting a mineral and testing it by comparison in turn with each of the testing implements, usually in the order in which they appeared on the hardness scale. The other strategy, one used by most of the children, consisted of a variation of this method and involved selecting a testing device which was then used to test all five minerals in turn before proceeding to the next device with which the entire process was repeated.

Regardless of the strategy used, however, all of the children tended to carry out more tests than theoretically were required, that is, they did not stop when they came to a test which 'worked'. Several reasons for this may be postulated. First, the clarity of presentation of the intended strategy as indicated to the children via the activity sheet might be questioned, particularly in view of the fact that both children and professional geologists appear to have experienced similar problems in interpreting the written instructions. Initially, for the children, this presented a significant source of confusion and although the teachers attempted to clarify the procedure, the point was not dwelt upon to any great degree. However, once the children obtained an initial understanding of the logical reasoning underlying the nature of the hardness scale they then appeared still to adapt it in accordance with their own perspectives, consequently 'distorting' the intended strategy.

Second, children, in generally carrying out more than the minimum number of steps required might in fact be reflecting their own reality in that they were not really operating within the terms of reference of a dichotomous framework, but were looking, instead, for 'degrees' of scratching or breaking. In other words, they were applying more than one criterion and applying these in relative fashion, a situation which necessitated carrying out additional tests in order to come to a conclusion. All in all, the fact remained that in general the children's methods worked, a tribute to their resourcefulness and ingenuity.

It might be postulated further that the results which the children were able to obtain from the set task did not encourage them to apply an exclusively dichotomous procedure, as generally their own strategies enabled them to order many of the minerals correctly. In other words, their methods usually worked and thus their personal strategies were reinforced. In those instances where two minerals were close in hardness, however, such methods broke down because fine distinctions in depth of scratch or number of chips, for example, could not be determined accurately. Although, for certain of the children, this may have been a source of some confusion and frustration, apparently this problem was not universal enough or frustrating enough to cause them to question or to reevaluate their strategies, or the particular criterion being applied.

A further conclusion relative to children involved their behaviour operationally coupled with their behaviour during the testing situation. This may be stated as follows:

4. There appears to be congruence between children's verbalization of the concept of mineral hardness and their operational use of the concept; however, children's written responses to questions involving hardness generally are not congruent with their apparent understanding of the concept as expressed verbally and as manifested operationally during related mineral ordering activities.

Analysis of observational data revealed that children, such as Tim, who talked about hardness in terms of breaking, also applied breaking techniques during their actual determination of hardness of a given mineral. On the other hand, children such as Sam and Mike, who primarily manifested the scratching point of view, normally also applied the scratching criterion during mineral ordering activities. Similarly, as might be anticipated, children manifesting an intermediate point of view and procedure, Penny and Chuck for example, being observed to apply both the scratching and the breaking criterion in laboratory situations, also describing their activities in terms of both criteria.

A similar congruence did not exist in general between an understanding by the children of the hardness concept as expressed verbally or operationally and their written responses to test items which required them to identify the meaning of hardness in relationship to minerals. This conclusion corroborates the admonitory note by Adler (1965) who, as a result of investigating concept understanding among college students, suggested that a person should exercise caution when regarding the ability of students to select a correct verbal formulation of a concept as an assurance of their understanding of that concept. Vygotsky (1962) also suggested that although children are able to answer questions about scientific concepts correctly (as in this case) it should be remembered that "these concepts are schematic and lack the rich content derived from personal experience" (p. 108) which is achieved through further schooling, reading and exposure.

Although the evidence is admittedly sketchy, it would appear that superficial evaluation of a situation carries with it the potential of being very misleading due to the fact that differences between one's impression of what children know and what they actually believe may be very great, as an analysis of the present type reveals. The implications which may be derived from all of this cast doubt upon standard modes of testing in that such tests tend to be conducted in a manner which is somewhat cursory, while detailed testing and analysis might lead to quite different conclusions.

Teachers also need to be aware of the meaning children attach to the words which they use to describe concepts, particularly when such words are similar to or identical with their own or with 'correct' scientific terminology. Teachers may assume that both they and the children share a common structure of meaning on the basis of the fact that they hear the children using the same terminology as the teacher, the use of such terminology by the children being partly a result of true comprehension on their part but also partly as a form of mimicry, often being assumed to manifest true understanding. Words may flow beautifully, but true conceptual understanding may not really be identified by such a flow, facility with language so easily being mistaken for true expression of comprehension. In a similar fashion, a distinction needs to be drawn between the covert and overt aspects of what is occurring operationally with regard to manipulation of materials. For example, observation of the children during the scratching of a mineral specimen, coupled with their verbal descriptions which frequently included the word "scratching", could easily lead to the incorrect inference that they were using the test as intended. Investigation of the covert reality of the situation, however, presents a difficult task which requires a great expenditure of time and energy, an expenditure which, nevertheless, is sorely needed.

Although the general characteristics of the children's written performance might have been anticipated, the fact that so many of the children, regardless of perspective, selected the 'right' answer came nevertheless as a surprise, particularly in view of the fact that several responses reflecting the breaking point of view were included among the possible choices presented to the children. This outcome raises a question regarding the common assumption that if the list of responses to a test item includes alternatives which reflect the true understanding of the respondents, respondents will tend to select that response which resembles most closely their point of view. Since generalizations from this particular case cannot be made, further investigation of this problem of choice from alternatives seems warranted, its outcome having particular implication for researchers who study the nature of concept development and understanding on the basis of the use of forced-choice questionnaires.

Further investigation into test-taking from the point of view of the children also seems warranted; a full understanding of the processes by which children are able to discern the 'right' answer from amidst an entire plexus of information presented to them during the course of classroom instruction and activities would be helpful in optimizing the efficiency of teachers.

The present study adhered to the scientific definition of mineral hardness as a framework of reference for discussing children's understanding of the property. Only a few children, as mentioned, were observed to manifest primarily a scientific understanding of the concept of hardness of minerals congruent with the understanding and use of the concept by professionals in the field of geology, the acquisition of precisely such an understanding being the intent of the curriculum planner. An examination of the procedural techniques employed by children and by geologists engaged in carrying out similar mineral ordering tasks provided a further means for evaluating approaches manifested by the children during the determination of mineral hardness. The results of this analysis may be summarized as follows:

5. Procedural techniques pursued both by children and by geologists are essentially the same, differences between such procedures being related essentially to variations in levels of knowledge and experience being applied by individuals to the tasks.

Both children and senior professional geologists applied scratching techniques during determination of mineral hardness, the basis of the technique for children being derived from the information provided in instructions accompanying the hardness table with which they were provided. Both groups recorded derived observational data on the table in a similar manner often placing more than one mineral at the same level of hardness, an outcome which was not intended by the curriculum developers but which may be attributable to the lack of clarity in the formulation of the table and in directions for its use coupled with the nature of the specimens and the testing devices provided. In this particular case it appeared that modification of a standard hardness scale, which usually involves the use of single words or numbers arranged in order of increasing hardness (fingernail, coin .... glass; or talc, gypsum .... diamond) to include such information as "Can be scratched easily by the fingernail" and "Will scratch glass" appeared to complicate the task. Such helpfully intended 'simplifications' and emendations actually resulted in the table becoming more confusing and cumbersome, for as a consequence of the modification, more than one mineral was discovered to fill the criterion at each level, while the real intention had been to ensure that only one mineral could be recorded at any given level.

Both children and geologists were observed to 'feel' minerals after scratching them, a process which assisted in establishing the presence or absence of a scratch, a scratch often being detectable by feel even when it cannot be seen. Some differences in application of techniques and understanding were apparent in that geologists systematically rubbed off the sample after each scratching attempt while most children were inconsistent in the application of this procedure; geologists naturally were also aware of the several mineral components present in certain specimens and knew which of these to 'test'; children, however, often were unaware of the presence of more than one mineral variety in a compound specimen, and even when they did become aware of this complication, they did not have sufficient background knowledge to be able to identify which component of the specimen should be tested. Geologists, however, then went on to comment upon the relative nature of certain of the judgements involved and upon the imprecision inherent in some of the specified activities. They also commented about variations in degrees of hardness displayed by some of the minerals provided. The range of hardness of the test implements and the condition of the specimens being used, factors about which children had no knowledge but which were important to the outcome of the exercise also were noted by the professionals in the field. Geologists were observed consistently to apply other knowledge and experience to the task with which they were presented; mineral recognition, the making of distinctions between hardness, brittleness, and scratching being aspects which they brought to bear as a contribution towards their ability to make sense out of the exercise, thus not being impeded by the information and processing vacuum encountered by the children. Although the geologists recognized the difficulties inherent in the exercise, particularly the imprecise nature of it, none of them questioned the legitimacy of it, not one of them asking the question, "What do students get out of this exercise?" This study would seem to indicate that precisely this question needs to be asked about hardness determination activities in particular, and possibly about other science activities in general.

One reason for the unquestioning attitude towards the inclusion of a study of hardness of minerals from elementary school through to the university level may be due to traditional factors.

Mineral hardness has become a part of the 'folk-culture' ("It always has been included in the curriculum"; "I did it when I was in school"; "My father did it before me and his father before him.") associated with instruction in geology and with the training of geologists. For the latter, however, such training is basic and essential for a field worker and it must be stressed that a more rational and comprehensive hardness scale is used as a basis for their training. The fact that the application of the test outside of the profession is of limited practical use appears, however, to be largely ignored by school curriculum formulators.

Aside from the influence of tradition, several other reasons may have influenced the selection of this topic for inclusion in the elementary school science program. It is assumed that a good science program should include some study of the earth sciences. If the developer of the science curriculum is not a trained geologist he or she may look to other science programs for ideas for topics to be included in the program, such a route invariably leading to rocks and minerals. Similar results may emerge if a curriculum developer with a background in geology is involved, for such a background must inevitably have included activities which dealt with mineral hardness; that person's own training may thus lead to inclusion of hardness testing in a basic introductory course involving minerals. The topic is also seductive for the science educator in that it is one of the few 'simple' earth science activities which can involve children directly in a 'discovery' activity or in science 'processing', activites which all are currently in vogue as far as elementary science teaching is concerned. "Discovery of what" and "activity for what" are important additional questions, however, which often seem to be overlooked during curriculum formulation.

A further conclusion which emerged from the study may be stated as:

6. Oversimplification of scientific concepts and techniques for children can, in fact, complicate tasks rather than simplify them.

The hardness scale introduced in the Minerals and Rocks unit used testing implements which may commonly be found in elementary schools or which may be obtained with little difficulty. These simple instruments carry with them an element of imprecision and their use often renders the experimenter unable to differentiate between minor differences in hardness between the mineral specimens provided, the experimental task thus being rendered more complicated. Another example of such over-simplification is to be encountered in the groupings of minerals used in the hardness exercise. In an attempt to control the difficulty level, only five minerals were provided for testing. By limiting the number of minerals, the total hardness range and hardness intervals were reduced, thereby increasing the inherent difficulty levels for the exercise. The simplification of the hardness scale which was attempted in addition rendered it more ambiguous and it thus failed to yield an adequate determination of an order for the given minerals.

The concept of hardness as it applies to minerals provides a good example of a superficially simple phenomenon which in effect encompasses factors of subtle complexity, a factor which curriculum developers continue to ignore for many geologists in training experience difficulty in applying the mineral tests which children are expected to apply with instant ease and success. As discussed earlier, hardness determination carries with it a considerable possibility for encountering variation within and between the characteristics of particular minerals. For example, minerals are often identified as a specific variety while, in fact, they may show considerable variation in composition -- a fact which generally is recognized by geologists, compositional ranges generally being defined rather than unique specific compositions. A calcite or fluorite specimen may well be identified as such commonly, although few samples are actually pure specimens, as might well be expected under natural conditions. The testing tools also displayed quite a range of hardness, which depended upon the composition of the steel, the manner in which the steel was tempered and the manner in which the implement was cut from the bar from which it was made. As a result, variations in the crystal grain of the testing implement influences the manner in which it will interact with the mineral being tested. The overall consequences of the influence of all of these factors is that the physical characteristics of both the implement and of the mineral display a wide variation of which, in order to make the testing implements 'work', a full understanding is required as far as both implements and specimens are concerned, something which geologists can comprehend and apply but which children cannot with facility because they possess neither the required knowledge nor the experience. In summary then, in attempting to simplify the tasks, the curriculum developers unintentionally have made the task more difficult, for information which might assist in improving accuracy has been eliminated.

This conclusion has important implications for curriculum developers, teachers and science educators. It appears that greater consideration needs to be given to the consequences of attempting to simplify a task. Obviously, the use of familiar materials such as pennies and files, or the modification of hardness scales does not necessarily make the task easier for children. Perhaps educators under the influence of Bruner's dictum that 'anything can be taught to anybody if it is presented at the right intellectual level' coupled with their concern with responding to Piaget's defined stage of 'concrete operations' have responded too liberally and uncritically and now need to analyze the results of the application of such dicta with greater precision.

Additional Implications

The Reality of Science

The example epitomized by classroom activities involving a study of mineral hardness represents a typical example of a 'slip twixt cup and lip' for, despite the dedication and diligence of all personnel involved in the construction of the exercise 'things went wrong'. The activities were developed with highest application of the levels of honesty and integrity, were taught enthusiastically and conscientiously, and the children exercised commendable effort in attempting to secure something from the exercise, yet little was achieved and much 'stumbling in the dark' transpired. We, therefore, have to ask ourselves about the extent to which similar hidden problems exist in other areas of science which involve the application of 'simple straightforward' exercises, exercises which may be leading to little more than the propagation of misconceptions. The implications for curriculum developers with respect to the extent of the discrepancy between intent and product need little further explication, this study being a simple encapsulated example of what can transpire between formulation, implementation and apparent evaluation of a project.

Hardness as defined geologically consists of a series of steps which have an approximately logarithmic relationship. Thus the magnitude of any step in the scale increases rapidly and encompasses a quite different absolute range. A determination of hardness also depends on the manner in which the mineral is scratched, with or against the grain, as has been mentioned. However, the property of hardness as it applied in this particular exercise constitutes a prime example of a parameter which is being determined in an apparently unimpeachable scientific fashion and in a quantitative way, when in fact such a determination is a somewhat subjective and qualitative thing. To claim or present such determinations as absolute constitutes a distortion of scientific principles, which although it is a widely acceptable distortion, leads students astray. Hardness as a physical property is one of the poorer examples to choose in trying to convey to children a sense of reliability with respect to a 'scientific' repeatable test, especially in view of the nature of the subjectivity, vagueness and somewhat arbitrary nature of particular aspects of this application of a modified Mohs scale. This particular case manifests the danger of taking a subtle and complex concept and presenting it as though it could be applied with a great degree of reliability -- the message which, in effect, is conveyed to the children. They look for absolutes, for go no-go criteria, even though the very nature of the materials with which they are working mitigate against the possibility of reaching such conclusions. In no instance was it pointed out that the concept of hardness as taught was applicable, and then it was treated in only a very limited fashion. We have to ask whether children might go on to consider that a leaf has a 'hardness of one' solely because it can be scratched by a fingernail. The suggestions presented to the children through the exercise may, in effect, create such confusion that more damage than good may be created.

Although many curriculum developers have had long experience with the relative nature of many aspects of science, this appreciation often does not percolate down to the details of exercises designed to convey the spirit of scientific investigation, science still often being represented as an expression of unimpeachable criteria applied on an absolute basis. Science, inappropriately presented, often conveys the impression that investigation may only be carried out with the tools which are put at our disposal when, often, the tools themselves may prove to be inadequate. The history of science is a history of "let us find the tools and we can complete the job". If, on the contrary, students are not provided with or are unable to find the proper tools, they may respond in a frustrated rather than in a logical fashion, solely because the opportunity or instructional system provided to deal with the problem is inadequate for the job, not because they themselves are burdened with an intrinsic intellectual inadequacy.

Unfortunately, this situation is coupled with the requirement that they are required to discover an absolute answer to a relative question.

What Is It All About?

The study of rocks and minerals might be cited as but one example of the many topics taught in science to which children are exposed solely on the basis of its definition as a 'good thing'. Curriculum formulators construct the program, teachers teach it, and children struggle with it. The question must be asked: What is it all about? In the case of rocks and minerals the reasons underlying the rationalization of the decision for inclusion of the unit in the elementary science program may take the form of the following general type: (1) It is felt that children must study some earth sciences; (2) The earth is made of but rocks and minerals; consequently the study of rocks and minerals should be included!, and (3) A conventional way of studying rocks and minerals is to scratch them, streak them and so on, therefore, include this topic!

Yet another enticing aspect of the topic revolves around its potential for actively involving children in the learning of science. The extent to which this factor determines what is to be taught in science in the schools coupled with the assumption that the use of specialized equipment, apparatus and materials is a necessary adjunct to science merits close scrutiny. Children not only did not learn much 'content' during involvement with this unit on minerals and rocks, but any content which they did learn might be of questionable value because of the particular nature of the exercise and the distortions inherent in its application.

Although one intention of the exercise was to provide children with a basic knowledge which they could then apply to their personal collections of minerals, little evidence emerged which suggested that any of the children indeed had collections, their interest in individual rocks and minerals, which some of them had picked up, being centered around pretty colours and interesting shapes, with no indications that the desire to make personal collections was developing. The need perhaps exists, then, to begin looking at the curriculum from the point of view of choosing those things which have the broadest application in the lives of citizens, children only later concentrating on those things which have a fairly limited, specialist and esoteric character.

Science Processing

The process-content debate in elementary school science continues with specific curricula placing special emphasis upon either one or the other, or upon stressing them equally. The Minerals and Rocks unit, as studied, could be classified primarily as a unit which emphasises process in that children were required to be engaged with materials in classifying, observing and inferring exercises. The question still remains, however, as to the purposes or goals of the exercise. In this particular case, children did not have adequate background knowledge, experience, or the levels of finesse required for effective processing. Part of the common folk-lore of science education is that programs should be activity-oriented; nevertheless, we are still obliged to ask whether such an approach is really any more effective than the rote learning of factual data which it has replaced. Educators, curriculum developers and teachers assume, on occasion, that children will come to an understanding of concepts by virtue of becoming involved in their application, even though the quality of involvement may become overlooked. We must accept that the possibility still exists that, in doing 'busy' work, children may well end up with neither content, understanding or comprehension, nor a true appreciation for the manipulation or processing involved in an exercise. The Minerals and Rocks unit consisted of a highly process oriented sequence, much observing, classifying and inferring being involved. However, the pursuit of observing and classifying themselves might well constitute exercises in futility unless significant and lasting results are achieved, for simple dedication to the process approach is something which cannot succeed in isolation.

In terms of its face value, this exercise is unimpeachable. The children are given concrete objects and familiar tools with which to manipulate the objects; the manipulation involves observation, and inferences drawn from observation involve classification. From the point of view of all the definitions we have of science it is a 'perfect' exercise; from the point of view of reality it is very questionable.

Having then examined this concept and exercise in detail we need to ask ourselves about the extent to which exercises of this nature epitomize what may well be a general manifestation of an approach to science in 'science education'. Furthermore, if this problem obtains with respect to science which is by its very nature concrete, definite and circumscribed, what implications might such a study as this have for areas which deal with more complex concepts such as 'values' in social studies?

The difficulties encountered by children in their study of rocks and minerals would suggest that, although involvement with a superficially simple exercise would seem to be indicated, in fact a very sophisticated level of knowledge, skill and experience is required from the outset in order for successful completion of the set tasks to be achieved. Thus the children, inadequately prepared as they were for the activity, could not be expected to possess or acquire the background necessary to deal with the prescribed tasks, tasks of an almost identical nature proving equally difficult for some students at the university level. Such realities being accepted, coupled with the questionable nature of the usefulness and significance of the topic, lead inevitably to a questioning of the appropriateness of inclusion of the study of mineral hardness in the elementary school curriculum. Since children do not possess sufficient background to deal with the topic adequately, the inclusion of such activities in an elementary school program would seem to represent, at best, exercises which keep children busy and actively involved and little else, a situation which probably results in some of them acquiring understanding of concepts purely by chance and, at worst, constitutes a waste of time for everyone concerned. A general examination of the utility of including the study of mineral hardness at any level, as traditionally presented, would seem appropriate, but if such an examination results in support for the suggestion that such a series of exercises be eliminated, what is to replace them, and how is the replacement exercise itself justified and rationalized unless it is subjected to the same scrutiny and analysis as the exercise which it has replaced?

Recommendations

The following recommendations stem directly from the conclusions which derive from the study:

1. The formal study of mineral hardness is inappropriate for young children and should not be included in the elementary school science curriculum. Young children do not possess the knowledge or practical experience required to deal adequately with the concept. Furthermore, the utility of the concept is questionable, its applicability dubious and the technique, especially as implemented, inadequate.

2. Curriculum developers need to attend in greater detail to the belief systems of children, taking them fully into account when designing science activities for the elementary school science program. The successive stages involved in science exercises should be rooted firmly in the belief systems of children, and curriculum formulators need to consider the extent to which inherent belief systems may be modified in the direction of the 'truth'. If, however, the belief systems are such that they are not amenable to modification without resorting to too sophisticated a series of procedures, then perhaps the concepts requiring modification of the belief system would be better left for consideration at a later time. Teachers also need to become more aware of children's belief systems and should take these into account during instruction, the latter being particularly true in instances which require a suspension or modification of an

everyday common-sense belief or understanding in order that a more formal scientific approach may be examined and developed.

3. Laboratory sequences should be examined critically to ascertain whether the intent of the curriculum formulator is actually and critically realized by the end of the exercise. In-depth examination of concept formulation and concept attainment resulting from such sequences should be undertaken in order to determine actual learning outcomes. Although costly in terms of time and energy such analyses could result in information which allows for modification of exercises such that meaningful learning occurs and that unsuitable exercises may be eliminated.

4. The nature of the materials used in science activities, is in need of critical analysis, analysis which should involve, in particular, the nature and precision of measuring devices and the sequence in which they are introduced. Care must be taken in any attempt undertaken in the 'simplification' of procedures in order to ensure that this does not actually result in the complication of exercises and procedures through the elimination of important information or through the significant alteration of techniques. Attention must also be given to the maintenance of a proper match between the measurer and the thing being measured.

5. A better balance between content and process within the context of elementary school science activities needs to be achieved. Processing without content can be meaningless and may result in activities which might well be considered little more than 'busy' work. All engaged in science teaching need to become more aware of what really is being learned by children during

their active involvement in 'sciencing'. The assumption that content will be learned merely as the result of being involved in science activities clearly is not always valid. Circumstances exist in which children need to rely on previous knowledge and experience in order to make sense out of processing. Curriculum formulators and teachers need to be more aware of this, taking the situation fully into account when developing and planning activity-oriented science experiences.

Suggestions For Further Research

The following suggestions for future work emerge directly from the conclusions:

1. Additional observational studies which focus on children's understanding of physical properties of minerals in general and hardness of minerals in particular need to be conducted. Such studies are required in order that insight may be gained into the factors in this clearly circumscribed area. Further clues may then be yielded with respect to the relationship between intent and realization of curricular elements, clues which may also aid in meaningful curriculum formulation in other areas.

2. A determination of the appropriate grade-level for introduction of the concept of mineral hardness requires definition. The appropriateness of including the particular approach, as implemented and studied, for the purpose of training in the identification of mineral hardness should be reevaluated. What may be appropriate for inclusion in the specific

training program of professional geologists may not necessarily be appropriate for others, particularly young students, especially when the exercise has been simplified and modified to the point of distortion.

3. Additional in-depth observational research into concept development in children engaged in classroom science activities involving other areas of concept acquisition such as magnetism, light and electricity would seem warranted. Such information regarding concept acquisition in classroom settings would provide further valuable information which presently is not available. Exercises relating to the phenomenon of magnetism have features and characteristics closely similar to those associated with exercises relating to the study of hardness in that the 'action' is simple and clear, but the concept involved is subtle and complex, being understood but poorly even by many physicists. The study of magnetism, nevertheless, is as pervasive an element of elementary school science curricula as is the study of mineral hardness.

4. The precise reasons for decision-making relating to the inclusion of given topics in elementary school science programs needs to be examined more critically. A study of the 'folk-cultures' of physics, chemistry and biology, as well as geology, coupled with an examination of the curriculum development process might provide important information regarding criteria used in the decision-making process as it relates to the formulation of science programs.

5. The manner in which children are tested about their knowledge and understanding of science concepts, and the effectiveness of these procedures both under normal classroom situations and during formal research investigations calls for further examination. Studies of the discrepancies between the intent and reality during the testing of children could provide valuable information for the formulation of more effective tests, especially where such involve laboratory activities or 'processing'.

Comments on Methodology

Advantages of the Approach Adopted for the Study

Direct participant observation was found to provide an excellent means for studying science concept development in the natural classroom setting. Very little is understood about the manner in which formal learning occurs in such a setting since science education researchers traditionally study concept development through the use of paper and pencil tests, such testing generally being carried out in quite formal settings. The experience of this study clearly indicates that it is possible to enter a classroom to identify significant problems and to gather data about these problems as these relate to concept development. A major advantage of conducting research into problems which emerge from concurrent observation of children as they go about their normal science activities is that the problems identified are more likely to be 'real' problems rather than artificial ones devised by someone quite divorced from the setting.

Several aspects of the methodology which were adopted also were attractive from the point of view of the teachers:

1. They became interested in the nature of the study and felt that it made eminent sense to study children on an extended time basis in their natural environment.

2. The research was seen as having great potential value for teachers as they were well aware of the fact that often what they thought was being taught was not actually what was being learned by the children, any insight into this discrepancy being welcomed.

3. The study focused primarily on the students rather than on the teachers, a situation which was less threatening to the latter.

4. The observer adjusted to the existing classroom schedule causing minimal disruption of classroom procedures, the latter constituting a factor of great concern to some teachers, particularly when the research project is of long duration.

5. Only one 'outsider' was involved in the investigation as opposed to a team of researchers, and the project did not require the use of large scale technical support, another potentially disruptive parameter.

All of these circumstances facilitated the entry process for the investigator and contributed to a very positive relationship with everyone involved.

Concerns Regarding the Approach

Upon reflection, several concerns regarding details of methodology emerged and factors relating to these concerns may have the potential of limiting the usefulness of this particular approach to the investigation of concept development in the elementary school. The first of these concerns relates to available time, a major variable which a researcher needs to consider in assessing the amount of data to be collected. The processes of problem identification, data collection, reflection, ongoing data analysis, and verification collectively require prolonged periods of involvement in given settings. In the case of the elementary science class, this means that the class has to be engaged in studying a specific topic over an extended period of time, an uncommon situation in many classrooms. Science programs which move quickly from one topic to another are unlikely to provide an appropriate setting for research involving in-depth participant observation into concept development. Furthermore, science topics within a grade level often are taught in isolation, in non-related, non-integrated sequences, a grade four class for example, might possibly be engaged in the study, in turn, of the topics of electricity, growth and development, sound, and earth changes, often spending limited amounts of time on each topic. Such procedures preclude use by the researcher of the common practice of returning periodically to the class in order to gather more data related to the concept under study, often an important factor with respect to the possible ultimate success of the venture. Observation carried out in several classrooms in which the same program is being followed constitutes a procedure which not only allows for more total contact time with students but also provides greater opportunity for observing behaviour in a variety of circumstances. Although it also allows for the development of a broader data base, nonetheless, an extended period of observation within each classroom is critical to the securing of adequate and valid data.

A second major concern, that of problem identification, constitutes another area which is also affected by the time factor. Since one significant advantage to be gleaned from qualitative research consists of the possibility of the discovery of problems and hypotheses, a specific research problem often is not determined before the investigation is well under way, significant problem areas emerging concurrently with ongoing observation. In my own case, although I entered into the research with an initial focus concerning the problems likely to be encountered, I can attest to strong feelings of doubt and concern when, after completion of the first phase of classroom observation, I was still in the position of having to identify and abstract a specific problem from the midst of a mass of observational data. Although the pursuit of this process eventually allowed a 'meaningful' problem to emerge, there were many anxious moments when the thought arose that the unit might be completed before any specific problem emerged.

It would seem that we have to accept the fact that when problems are intially undefined, or poorly so, longer periods of field time may be required before delineation of a significant issue occurs. I suspect that the usual length of time spent by an elementary science class on any one concept may be one important limiting factor upon the degree of freedom available for the exploration and discovery of significant, but normally concealed problems.

A final concern deals with investigator bias and objectivity. Aside from the necessity of continually applying techniques which assist observers in maintaining a proper distance between the object of study and themselves, the challenge and necessity exists for the observer to remain open to different perspectives and, very importantly, to be able to 'make the familiar strange'. Acquiring this ability to 'suspend' knowledge or to 'bracket' in order to adopt other viewpoints and perspectives represents a major challenge to the investigator. During the course of this study my own knowledge and background as it related to the concept of mineral hardness interfered for a time with my ability to interpret the actual meaning of hardness as it was understood and translated into operational activities by the children. It was only after some six months of struggling with pages of transcript data that I suddenly realized that the children were interpreting the presence or absence of a scratch quite differently from the manner in which I had been assuming that their interpretation had been carried out, although they often used words and actions similar to my own and which were associated with the scientific perspective. Once this insight had been achieved it presented the key to unlocking a new phase of data analysis and allowed me to develop a 'sensitizing concept' (Blumer, 1962) related to the understanding which the children had of mineral hardness. This experience has led me to empathize with some skeptics who question whether or not educators can effectively use this methodology in view of the fact that they are 'too familiar with their trade.[1] I, too, now wonder how many science educators holding concepts which have been thoroughly internalized on the basis of a scientific point of view are capable of suspending this knowledge, able to make the familiar strange, and able to assume the perspective of a child.

In this study methodology developed on a parallel basis with observation. Methodology and approach did not appear to crystallize at any specific juncture but, rather, the system evolved gradually into a viable, functioning entity. Methodologically, we in science education need to consider and apply alternatives which are complementary to the approaches traditionally encountered in research ventures, ventures which commonly emphasize a style dedicated solely to the solution of predetermined problems. Standard operational definitions are then applied, predetermined data is gathered and ultimate findings are often only too predicatable. These procedures furthermore, are often carried out in isolation from the reality of classroom life. In such research the best surprise is often no surprise; such cannot be said of the present study. The pleasant surprise in this instance was that the study was full of surprises which were tempered by doubts and uncertainties during their revelation and emergence. I have learned from this experience that I am just beginning to learn about a very subtle and complex area, the words of Sir Isaac Newton being most evocative of my own feelings concerning my venture:

> I do not know what I may appear to the world but to myself I seem to have been only like a boy playing on the sea-shore, and diverting myself now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.

BIBLIOGRAPHY

BIBLIOGRAPHY

Adams, R. N., & Preiss, J. J. Human organization research. Homewood, Illinois: The Dorsey Press, Inc. 1960.

Adler, L. K. Do they mean what you say? Science Teacher, 1965, 32 (2), 23-25.

Ashbaugh, A. An experimental study for the selection of geological concepts for intermediate grades. Unpublished doctoral dissertation. University of Georgia, 1964.

Askham, L. R. The effects of plants on classification behavior in an outdoor environment. Journal of Research in Science Teaching, 1976, 13 (1), 49-54.

Becker, H. S. Problems of inference and proof in participant observation. American Sociological Review, 1958, 23 (6), 652-660.

Becker, H. S., & Geer, B. Participant observation — the analysis of qualitative field data. In R. N. Adams & J. J. Preiss Human organization research. Homewood, Illinois: The Dorsey Press, Inc., 1960.

Becker, H. S., & Geer, B. Making the grade. New York: Wiley, 1968.

Blumer, H. Society as symbolic interaction. In A. M. Rose (Ed.), Human behavior and social processes. Boston: Houghton Mifflin, 1962.

Bogdan, R. Participant observation in organizational settings. Syracuse: Syracuse University Press, 1972.

Bogdan, R., & Taylor, S. J. Introduction to qualitative research methods. Toronto: John Wiley & Sons, 1975.

Bowen, B. L. The need for paradigms in science. Science Education, 1975, 59 (3), 423-430.

Bruner, J. S., Goodnow, J. J., & Austin, G. A. A study of thinking. New York: Wiley & Sons, 1956.

Bruyn, S. T. Human perspective in sociology. Englewood Cliffs: Prentice Hall, 1966.

Burling, R. Cognition and componential analysis: God's truth or hocus pocus? American Anthropologist, 1966, 20-28; 120-122.

Cicourel, A. V. Method and measurement in sociology. New York: Free Press, 1969.

Colby, B. N. Ethnographic semantics: A preliminary survey. Current Anthropology, 1966, 7, 3-32.

Cohen, M. The effect of natural small-scale geologic features on the concepts of fluvial geology among fifth and sixth grade students. Unpublished doctoral dissertation. Cornell University, 1968.

Davis, J. Teacher, kids, and conflict: Ethnography of a junior high school. In J. P. Spradley & D. W. McCurdy, The cultural experience: Ethnography in complex society. Toronto: Science Research Associates, 1972.

Dictionary of Geologic Terms. American Geologic Institute, New York: Anchor Books, Inc., 1974.

Dean J. R., Eichhorn, R. L., & Dean, L. R. Limitation and advantages of unstructured methods. In G. J. McCall & J. L. Simmons (Eds.), Issues in participant observation. Don Mills: Addison-Wesley Publishing Company, 1969.

Dennis, D. M. The introduction of concepts of kinetic molecular theory to children. Journal of Research in Science Teaching, 1966, 4, 106-111.

Denzin, N. K. Sociological methods. Chicago: Aldine, 1970.

Dodge, M. W. Selling audio-visual: A participant observation study of the school media specialist. Unpublished doctoral dissertation. Syracuse University, 1973.

Doyle, J. Helpers, officers and lunchers: Ethnography of a third grade classroom. In J. P. Spradley & D. W. McCurdy, The cultural experience: Ethnography in complex society. Toronto: Science Research Associates, 1972.

Dunkin, M. J., & Biddle, B. J. The study of teaching. Toronto: Holt, Rinehart and Winston, Inc., 1974.

Erickson, F. Some approaches to inquiry in school-community ethnography. Anthropology and Education Quarterly, 1977, 9 (2), 58-69.

Erickson, G. L. An analysis of children's ideas of heat phenomena. Unpublished doctoral dissertation. University of British Columbia, 1975.

Feer, M. Informant — ethnographers in the study of schools. Human Organization, 1975, 34 (2), 157-162.

Filmer, P. New directions in sociological theory. Cambridge, Mass: MIT Press, 1972.

Filstead, W. J. (Ed.). Qualitative methodology: Firsthand involvement with the social world. Chicago: Markham Publishing Co., 1970.

Fitzsimmons, S. J. The anthropologist in a strange land. Human Organization, 1975, 34 (2), 183-196.

Frazer, D. A., Ghatala, E. S., & Klausmeier. Levels of concept mastery: Implications for instruction. Educational Technology, 1972, 12, 23-29.

Gage, N. L. Teacher effectiveness and teacher education: The search for scientific basis. California: Pacific Books, 1971.

Gallagher, J. J. Classroom observation. A.E.R.A. Monograph Series on Curriculum Evaluation, No. 6. Chicago: Rand McNally, 1970

Gait, R. I. Exploring minerals and crystals. New York: McGraw Hill, 1972.

Gardner, P. L. The structure of science education. London: Longman, 1975.

Garfinkle, H. Studies in ethnomethodology. Englewood Cliffs: Prentice Hall, 1967.

Geer, B. First days in the field. In G. J. McCall & J. L. Simmons (Eds.), Issues in participant observation. Don Mills: Addison-Wesley, 1969.

Gillespie, J. P. A study of concept development and communication abilities in young children using variations in leaf morphology. Journal of Research in Science Teaching, 1972, 9 (1), 57-64.

Glasser, B. G., & Strauss, A. L. The discovery of grounded theory: Strategies for qualitative research. Chicago: Aldine Publishing Co., 1967.

Gold, R. L. Roles in sociological observation. In G. J. McCall & J. L. Simons (Eds.), Issues in participant observation. Don Mills: Addison-Wesley Publishing Co., 1969.

Goodenough, W. H. Culture, language and society. Reading, Massachusetts: Addison-Wesley Publishing Co., Inc., 1971.

Gussow, Z. The observer-observed relationship as information about structure in small group research. Psychiatry, 1964, 27, 236-247.

Harlen, W. The development of scientific concepts in young children. Educational Researcher, 1908, 11 (1), 4-13.

Harris, M. The rise of anthropological theory. New York: Thomas Y. Crowell Co., 1968.

Haung, I. Children's conceptions of physical causality: A critical summary. Journal of Genetic Psychology, 1943, 63, 71-121.

Heyl, J. D. Paradigms in social science. Society, 1975, 12 (5), 61-67.

Harlbut, C. S., Jr., (Ed.). The planet we live on. New York: Harry N. Abrams Inc., 1976.

Hymes, D. H. Discussion of Burling's paper: Cognition and componential analysis: God's truth or hocus pocus? American Anthropologist, 1966, 116-119.

Hymes, D. H. Qualitative/quantitative research methodologies in education: A linguistic perspective. Anthropology and Education Quarterly, 1977, 8 (3), 165-176.

Inbody, D. Children's understanding of natural phenomena. Science Education, 1963, 47 (3), 270-278.

Inhelder, B., & Piaget, J. The early growth of logic in the child. London: Routledge and Kegan Paul, 1964.

Issacs, S. Intellectual growth in young children. New York: Harcourt Brace, 1930.

Janke, D. L. The concept currency of K-12 science textbooks relative to earth science concepts. Unpublished doctoral dissertation. University of Wisconsin, 1969.

Janke, D. L., & Pella, M. O. Earth science concept list for grades K-12 curriculum construction and evaluation. Journal of Research in Science Education, 1972, 9 (3), 223-230.

Johnston, A. M., & Burns, P. C. Research in elementary school curriculum. Boston: Allyn and Bacon, Inc., 1970.

Jungwirth, E. An evaluation of the attained development of the intellectual skills needed for "understanding of the nature of scientific enquiry" by B.S.C.S. pupils in Israel. Journal of Research in Science Teaching, 1970, 7, 141-151.

Kahn, R., & Mann, F. Developing research partnerships. In G. J. McCall & J. L. Simons (Eds.), Issues in participant observation. Don Mills: Addison-Wesley, 1969.

Kaplan, A. The conduct of inquiry. Scranton, Pennsylvania: Chandler Publishing Co., 1964.

King, W. Studies of children's concepts and interests. British Journal of Educational Psychology, 1961, 32, 1-20.

Rosenshine, B., & Furst, N. The use of direct observation to study teaching. In R. M. W. Travers (Ed.), Second handbook of research on teaching. Chicago: Rand McNally Publishing Co., 1973.

Sandy, P. R. Emerging methodological developments for research design, data collection, and data anlysis in anthropology and education. In C. J. Calhoun & F. A. J. Ianni (Eds.), The anthropological study of education. The Hauge: Mouton Publishers, 1976.

Schatzman, L., & Strauss, A. L. Field research: Strategies for a natural sociology. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1973.

Schutz, A. The phenomenology of the social world. (G. Walsh, trans.) Evanston, Illinois: North Western University Press, 1967. (originally published, 1932).

Schwartz, G., & Merten, D. Participant observation and the discovery of meaning. Philosophy of the Social Sciences, 1971, 1, 279-298.

Schwartz, M. W., & Schwartz, C. G. Problems in participant observation. The American Journal of Sociology, 1955, 60 (4), 343-353.

Scriven, E. G. An analysis of the types of concepts used by fourth through ninth graders to explain meaning. Journal of Educational Research, 1968, 62 (4), 153-156.

Shulman, L. S., & Tamir, P. Research on teaching in the natural sciences. In R. M. W. Travers (Ed.), Second handbook of research on teaching. Chicago: Rand McNally College Publishing Co., 1973.

Silano, A. A. The spontaneous remarks of children concerning magnetic phenomena. School Science and Mathematics, 1952, 52, 477-482.

Simon, A., & Boyer, E. G. (Eds.). Mirrors for behavior II. Philadelphia: Classroom Interaction Newsletter, 1970.

Sindell, P. S. Anthropological approaches to the study of education. Review of Educational Research, 1969, 39 (5), 593-605.

Smith, L. M. The microethnography of the classroom. Psychology in the Schools, 1967, 4 (3), 216-221.

Smith, L. M. An evolving logic of participant observation, educational ethnography and other case studies. Review of Research in Education, 1977, 6, 626-377.

Kraft, R. H. P., & Smith, L. M. Four evaluative examples: Anthropological, economic, narrative, and portrayal. A.E.R.A. monograph Number 7. Chicago: Rand McNally College Publishing Co., 1974.

Lasley, T. J. Perceived student misbehavior within the context of classroom interaction: A participant observation study. Unpublished doctoral disseration. The Ohio State University, 1978.

Lofland, J. Analyzing social settings. Belmont, California: Wadsworth Publishing Inc., 1971.

Lutz, R. W., & Ramsay, M. A. The use of anthropolocial field methods in education. Educational Researcher, 1974, 3 (11), 5-9.

Malinowski, B. Argonauts of the western pacific. London: Routledge, 1922.

Mason, B., & Berry, L. G. Elements in Mineralogy. San Francisco: W. H. Freeman and Co., 1968.

McCall, G. J., & Simons, J. L. (Eds.). Issues in participant observation. Don Mills: Addison-Wesley, 1969.

Mehan, H., & Woods, H. The reality of ethnomethodology. Toronto: John Wiley & Sons, 1975.

Mishler, E. G. Meaning in Context: Is there any other kind? Harvard Educational Review, 1979, 49 (1), 1-17.

Naroll, R., & Cohen, R. (Eds.). A handbook of method in cultural anthropology. New York: Columbia University Press, 1970.

Nash, R. Pupil's expectations for their teachers. Research in Education, 1974, 12, 47-61.

Nelson, P. A. Concepts of light and sound in the intermediate grades. Science Education, 1960, 44, 142-146.

Nussbaum, J., & Novak, J. D. An assessment of children's concepts of the earth utilizing structured interviews. Science Education, 1976, 60 (4), 535-550.

Oakes, M. Children's explanations of natural phenomena. New York: Teachers College, Columbia University, Contribution to Education, No. 926, 1947.

Parlett, M. R. Undergraduate teaching observed. Nature, 1969, Vol. 223, 1102-1104.

Parrott, S. Games children play: Ethnography of a second grade recess. In J. P. Spradley & D. W. McCurdy, The cultural experience: Ethnography in complex society. Toronto: Science Research Associates, 1972.

Pelto, P. J. Anthropological research: The structure of inquiry. New York: Harper and Row, 1970.

Peters, L. A. A classroom participant observation study of the behavior of selected high school students with a reading handicap. Unpublished doctoral disseration. Southern Illinois University, 1978.

Piaget, J. The child's conception of the world. London: Routledge and Kegan Paul Ltd., 1929.

Piaget, J. The child's conception of physical causality. New York: Harcourt, Brace and Co., 1930.

Pike, K. L. Etic and emic standpoints for the description of behavior. In D. C. Hildum (Ed.), Language and thought. Toronto: D. Van Nostrand, 1967.

Pike, K. L. Language in relation to unified theory of the structure of human behavior. The Hauge: Mouton & Co., 1967.

Pinnar, W. F. Notes on the curriculum field 1978. Educational Researcher, 1978, 1 (8), 5-12.

Power, C. N. Competing paradigms in science education research. Journal of Science Education, 1976, 12 (6), 579-587.

Psathes, G. Ethnoscience and ethnomethodology. In J. P. Spradley (Ed.), Culture and cognition: Rules, maps and plans. Toronto: Chandler Publishing Co., 1972.

Ramsey, G. A., & Howe, R. W. An analysis of research. Science and Children, April, 1969, 6, 25-36.

Raven, R. J. The development of the concept of acceleration in elementary school children. Journal of Research in Science Teaching, 1968, 9, 201-206.

Robinson, P. E. D. An ethnography of classrooms. In J. Eggleston (Ed.), Contemporary research in the sociology of education. London: Methuen, 1974.

Romney, A. K., & D'Andrade, R. G. (Eds.). Transcultural studies in cognition. American Anthropologist, 1964, 66 (3), Part 2.

Rose, A. M. (Ed.). Human behavior and social processes. Boston: Houghton Mifflin, 1962.

Snow, R. E. Theory construction for research on teaching. In R. M. W. Travers (Ed.), Second handbook of research on teaching. Chicago: Rand McNally College Publishing Co., 1973.

Sorrell, C. Minerals of the world. New York: Golden Press, 1973.

Spitzer, D. R. What is a concept? Educational Technology, July 1975, 36-39.

Spradley, J. P. (Ed.). Culture and cognition: Rules, maps and plans. Toronto: Chandler Publishing Co., 1972.

Spradley, J. P., & McCurdy, D. W. The cultural experience: Ethnography in a complex society. Toronto: Science Research Associates, 1972.

Stubbs, M., & Delamont, S. (Eds.). Exploration in classroom observation. Toronto: John Wiley & Sons, 1976.

Sturtevant, W. C. Studies in ethnoscience. In J. P. Spradley (Ed.), Culture and cognition: Rules, maps and plans. Toronto: Chandler Publishing Co., 1972.

Tamir, P. The practical — a distinct mode of performance in biology. Journal of Biological Education, 1972, 6, 175-182.

Their, H. D. A look at a first grader's understanding of matter. Journal of Research in Science Teaching, 1965, 3, 84-89.

Travers, R. M. W. (Ed.). Second handbook of research on teaching. Chicago: Rand McNally College Publishing Co., 1973.

Turner, B. L., & Robb, G. P. Research in education: An introduction. Hinsdale, Illinois: Dryden Press, Inc., 1971.

Tylor, E. B. Primitive culture. London: Murray, 1871.

Vidich, A. J. Participant observation and the collection and interpretation of data. American Journal of Sociology, 1955, 60, 354-360.

Vygotsky, L. S. Thought and language. Cambridge, Massachusetts: MIT Press, 1962.

Voelker, A. M. Research on concept learning: An analysis. Occasional Paper Series — Science Paper 11, prepared for ERIC Center for Science, Ohio State University, Columbus Ohio, 1973.

Voelker, A. M. Elementary school children's attainment of the concepts of physical and chemical change — a replication. Journal of Research on Science Teaching, 1975, 12 (1), 5-14.

Walker, D. F. A naturalistic model for curriculum development. School Review, 1971-72, 80, 51-65.

Warren, R. L. Context and isolation: The teaching experience in an elementary school. Human Organization, 1975, 34 (2), 139-148.

Wax, M. L., Diamond, S., & Gearing, F. O. (Eds.). Anthropological perspectives on education. New York: Basic Books, 1971.

Webb, E., Campbell, D. T., Schwartz, R. D., & Sechrest, L. Unobtrusive measures: Non-reactive research in the social sciences. Chicago: Rand McNally, 1966.

Weisberg, J. S. The use of visual advance organizers for learning earth science concepts. Journal of Research on Science Teaching, 1970, 7, 161-165.

West, W. G. Participant observation in Canadian classrooms: The need, rationale, technique and development implications. Canadian Journal of Education, Vol. 2 (3), 1977, 55-74.

Whitten, D. G. A. A dictionary of geology. Great Britain: Hazel Watson and Viney Ltd., 1972.

Whyte, W. F. Street Corner Society (2nd ed.). Chicago: University of Chicago Press, 1955.

Wilson, S. The use of ethnographic techniques in educational research. Review of Educational Research, Winter 1977, 47, (1), 245-265.

Wolcott, H. F. The man in the principal's office. Toronto: Holt, Rinehart and Winston, Inc., 1973.

Wolcott, H. F. Criteria for an ethnographic approach to research in the schools. Human Organization, 1975, 34 (2), 111-127.

Woods, P., & Hammersley, M. (Eds.). School experience. New York: St. Martin's Press, 1977.

Yager, R. E. Priorities for research in science education: A study committee's report. Journal of Research in Science Teaching, 1978, 15 (2), 99-107.

APPENDICES

APPENDIX A

Concern of Anonymity In Conjunction with the Study

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This study could not have been completed without the close cooperation of everyone concerned: school board officials, science consultants, teachers and students. As a researcher I was allowed to participate freely in the daily activities of several classrooms, a situation which resulted in my being able to share in many aspects of classroom life, including the "ups and downs" of daily activities and becoming privy to information sometimes of a more private nature. For the protection of everyone associated with the study, it was decided to change the names of schools, teachers, and students, thus, any names which appear within the text of this thesis are ficticious.

Although permission was granted by the local school board to reproduce the instructional unit which served as the basis for the study and although it was initially suggested that the name of the school system need not be concealed but could be retained for purposes of identification of the source of the instructional material, it was finally decided that the more suitable course of action was to retain anonymity throughout the thesis. Permission to reproduce the unit still rests with the school board with which it originated. The author would therefore request that anyone wishing to adopt the unit contact her for the address of the school board concerned so that permission for its use may be obtained.

APPENDIX B

List of Specimens Used in Conjunction With Phase I and Phase II Interviews

Minerals, Rocks and Other Specimens

1 Lead
2 Talc
3 Iron
4 Mica (colourless)
5 Mica (brown)
7 Sulphur
8 Pyrite
10 Brick (red)
11 Concrete
12 Concrete
14 Brick (brown)
16 Pebble (cement)
18 Calcite
20 Schist
21 Quartz ("boat")
25 Gypsum
32 Granite (with Mica)
33 Obsidian
36 Sandstone (flat)
37 Shale (grey)
38 Slate (black)
39 Shale (red)
40 Halite
41 Calcite
42 Quartz
43 Fluorite
44 Basalt
45 Iron
48 Pumice
51 Granite (Biotite)
52 Granite (Hornblende)
53 Syenite
56 Gabbro
64 Basalt
66 Porphyry, Feldspar
70 Sandstone
71 Sandstone
72 Limestone
73 Dolomite
74 Shale
75 Greywacke
76 Quartzite
78 Slate (red)
79 Limestone (crystalline)
80 Dolomite (crystalline)
82 Schist (Talc)
83 Schist (Mica)
84 Gneiss (Garnet)
93 Chalk
96 Pebble (white)
101 Pebble (large)
110 Pebble (small, white)
111 Pebble (banded)
112 Pebble (round, red)

114	Conglomerate (small)
115	Pebble (small grey/black)
117	Pebble (small, red)
118	Pebble (small, black)
119	Pebble (flat, pink)
120	Pebble (large, red/white, banded)
122	Conglomerate (small)
123	Granite (small, pink)
124	Pebble (brown-agate sort)
125	Pebble (black/white, green, banded)
126	Pebble (black/red banded)
127	Conglomerate (large, red)
128	Pebble (rounded)
129	Pebble (Quartz, pink)
130	Pebble (large, smooth, creamy)
132	Quartz (pink)
136	Quartz (rose)

Fossils and Other Specimens

1	Bone
2	Clam (Cucullaen rockymontana)
3	Clam (Cucullaen rockymontana)
4	Brachiopod (Pentamerus oblongus)
5	Brachiopod (Atrypa reticularis)
6	Coral
7,15	Corals, round (Phillipsastrea verneuli)
9	Brachiopod (Leiorhynchus sp.)

10	Brachiopod (Hypothyridina venustula)
11	Shell (Meristella nasuta)
12	Brachiopod (Dinorthis anticostiensis)
13,14	Dielasma
15	Coral (red)
16	Coral
18	Graptolite (spiral) (Monograptus spiralis)
19	Graptolite (straight)
22	Rock with shells
23	Petrified Wood
24	Ammonite, large (Cadoceras falsum)
25	Rock with small shells
26	Brachiopod in rock
27,29	Barnacles on rock
30	Brachiopod (long,narrow)
32,105	Horn corals
33	Brachiopod in rock
35	Plaster of paris cast
102	Shell (small, spiral)
166	Trilobite (Bathyuriscus rotundus)
167	Fern (Alethopteris serli)
1850	Graptolite

APPENDIX C

Selected Phase I Interviews with Three Children — Curt, David and Paul

T1/1

Curt (8 years 1 month - completed grade 2.)

Curt: Wow! You do have lots of things. And, oh, it looks alike you even have some gold (pyrite).

Interviewer: Have you ever seen anything like that before?

Curt: No, but it's pretty heavy. I've never seen anything like this either.

Interviewer: What do you like about it?

Curt: I like this one because it's kind of shiny and I've noticed that it's a bit green too.

Interviewer: Can you tell me anything else about it?

Curt: Oh, yah, this an interesting flat one (4-Mica).

Interviewer: What's interesting about it?

Curt: Well, it's kind of flattish and funny.

Interviewer: What's happening?

Curt: It's scaling. Hey, this is a nice shiny one (Lead).

Interviewer: What do you think makes it shine?

Curt: It looks like it might be a mirror rock. (Uses magnifying glass)
Like litte peices of mirror stuck on. Sometimes it kind of seems like the moon.

Interviewer: In what way does it seem like the moon?

Curt: Well, actually like a meteorite.

Interviewer: What is a meteorite?

Curt: Well one of those big balls going right through space.

Interviewer: Have you never seen one?

Curt: No, but I love this yellow one (Sulfur). It's kinda of "what shamacallit", the stuff that has little blue things in it. Like styrofoam with holes in it. One hole has like a meteorite with all the little holes in it.

Interviewer: And look at 10 (brick).

Curt: 10 is like a brick. I think it _is_ a piece of brick.

Interviewer: What makes you say that?

Curt: It's the color of brick and it's hard like a brick and it feels like a brick on this part. It must have been something like a curved wall. Hey--this one (120-red/white/layered pebble) looks kind of like a shell or a clam. Hey--that one's (40-halite) an interesting one--it looks lika a piece of ice. I like this one (136-rose quartz) here.

Interviewer: Why do you like it?

Curt: Cause it kind of funny. These things are very very rare.

Interviewer: What do you mean by funny?

Curt: Well, it's kinda of like icing, like a piece of gigantic home-made popcicle and parts of it have been sucked, so it's just like ice on the white part and part has been sort of sucked.

Interviewer: What makes you think it's rare?

Curt: Well, I never really see these kind around.

Interviewer: How about 122 (Conglomerate)?

Curt: 122 looks like a piece of the moon.

Interviewer: In what way?

Curt: Here it is kind of bumpy. I think it's piece of gravel.

Interviewer: You mean if I went out on the street and found some gravel it would look like that?

Curt: Maybe.

Interviewer: Would it be all stuck together like that?

Curt: Probably.

Interviewer: Would it be more loose?

Curt: Well, it's more like cement actually. It's kind of like cement and you know they put rocks in cement.

Interviewer: Why do they do that?

Curt: I 'don't know, but in cement things-you know one of those things you park the car in front of? I've seen one of those broken and it looks just like this inside. I like this one (33-obsidian).

Interviewer: What do you like about it?

Curt: It's all shiny and black.

Interviewer: What do you think would make something so nice and shiny like that?

Curt: I don't know (studies it with magnifying glass).

Interviewer: Any clues? Does it still look shiny underneath the magnifying glass?

Curt: Yes, it's kind of like, you know, the tap-dancing shoes.

Interviewer: You mean paton-leather shoes?

Curt: Yes. This one is kind of like chalk (93 - Chalk).

Interviewer: What do you mean?

Curt: It's kind of white and it makes something like chalk dirt.

Interviewer: Is it a rock?

Curt: I don't know. I think it's chalk.

Interviewer: Do you think it belongs in this box with all the other rocks?

Curt: It's chalk. I don't know. I'm not too sure if it come from the ground or not.

Interviewer: That's an interesting point. Where do you think rocks come from?

Curt: Underground. [Burial idea?]

Interviewer: How did they get there?

Curt: Well, they probably formed sometimes around the ages of the dinosaurs. Maybe there were great big hunks of rocks and the dinosaurs when they stepped on them - some of the great big ones crushed it into pieces. [Outside intervention]

Interviewer: And what happened to the pieces?

Curt: Well, ------.

Interviewer: You mean some these rocks might have been some of the pieces that the dinosaurs broke up?

Curt: Yah.

Interviewer: That's an interesting theory. How do you think the rock got in the mountains?

Curt: Maybe it was all mud once and formed into rocks. That's how fossils are made. And you know from the dinosaurs ages when the fish died there were only their skulls and they sunk into the mud and made a print. And later it formed the rock.

Interviewer: How does it (rock) get harder and harder?

Curt: I don't know, but I read it in a book.

Interviewer: Where did you get the book?

Curt: I think it was one of our teacher's books.

Interviewer: Well, let's go back and talk about this one (101-large pebble) again.

Curt: I like this flat one. It might be good for skipping.

Interviewer: How do you think it got to be that shape?

Curt: I don't know, Maybe it got kind of crushed by something, It might have been a roundish rock like this one.

Interviewer: And it sort of got crushed?

Curt: Yah.

Interviewer: Supposing we crushed this rock. Would the pieces be roundish or sort of sharp?

Curt: Little pieces that were sharp. Maybe this was flattened and not crushed. Maybe it could have still been forming and maybe someone took some mud and shaped it up and let it form. [Human intervention]

Interviewer: Have you ever seen any other rock shaped like this?

Curt: Yah, in the Ozark Mountains I have, and some places over here I have, too. This is a nice little smooth brown one (112-red pebble). It looks kind of like a bean -a gigantic bean. It's brown like a bean, too

Interviewer: Notice anything you did'nt see before?

Curt: Well, parts of the colour have kind of chipped off. You know what-I think this might have been accidently dropped in a thick dye. [Human intervention]

Interviewer: How could we find out if that were true or not?

Curt: I don't know. If I had a microscope and knew what hard dye looked like-if it were like this---I could chip a piece off and put it under a microscope.

Interviewer: Do you think it it would be that colour all the way through or do you think it is that colour just on the outside-like paint?

Curt: Just on the outside like paint.

Interviewer: Perhaps we could break it and see (can't break it). What does that tell you about this rock?

Curt: Must be pretty hard. Do you have lead in here (in the collection)?

Interviewer: Would you recognize it? Why don't you look and see. (Doesn't find any) Perhaps you can find some other interesting pieces.

Curt: This one's (lead) interesting. It's kind of like the chalk except it's shiny like the black one or actually like the gold and green.

Interviewer: Is it the same kind of shiny stuff, do you think?

Curt: Maybe it's the same kind of shiny shuff as this except that it absorbed--except it reflects a different color. [learned?]

Interviewer: What would cause that?

Curt: I don't know. Close up it looks like a tiny piece of mirror. That's not a piece of lead.

Interviewer: How would you know lead if you saw it?

Curt: Well, I've got a piece of lead a bit smaller, but this is not as heavy. It just looks like lead.

Interviewer: Is everything that's heavy lead?

Curt: No.

Interviewer: If I had two heavy objects in my hand how would you tell the it one were lead and one weren't?

Curt: Well, if they were like stones, if one were like this and looked very very much like lead. Let me check it with mine (gets his piece). Now these two pieces don't weight the same so your's isn't lead. [Size criterion]

Interviewer: Is your's pure lead?

Curt: Yah.

Interviewer: Look at the white stuff, Do you think It's lead?

Curt: No.

Interviewer: How did the white stuff get in there?

Curt: I don't know.

Interviewer: Look at this (iron). Do you think it's lead?

Curt: No.

Interviewer: Why not?

Curt: It's a bit darker and it doesn't have any white mixed in it, but it's got a bit of brown mixed in it and it's also not as heavy. [Colour criterion]

Interviewer: Any idea what it could be?

Curt: No--I don't know very many names of rocks. But this one (slate-38) looks like coal.

Interviewer: Where does coal come from?

Curt: From the ground.

Interviewer: Is it all underground or on top?

Curt: Sometimes on top.

Interviewer: How did it get there?

Curt: I don't know.

Interviewer: Do you think coal is very old?

Curt: Probably. Look at this one (18-calcite). It's like a piece of glass with plastic over it. [Human intervention]

Interviewer: Anything else interesting about it?

Curt: It's kind of darkish on one side and lightish on the other.

Interviewer: Is it shiny?

Curt: A bit --along the edge.

Interviewer: Look at this one.

Curt: It's kinda neat. It's got little rocks in it. It would be good for throwing. This one (iron) is heavier than this (17-iron in rock) even though it's the same size.

Interviewer: What would cause that?

Curt: No---this one is probably a light mineral.

Interviewer: What's a mineral?

Curt: Well, it's hard to explain, It's kind of like a thing --things like 120 (red/white layered pebble) are just rocks. Mineral are things different than just plain rocks. Like 136 (rose quartz) is probably a mineral because it's different than just a plain rock.

Interviewer: In what way is it different?

Curt: Well, it's not the same colour or anything. [Colour criterion]

Interviewer: Can you find any other minerals in here? What about 112 (red pebble)? Is it a mineral or would you put it with the rocks?

Curt: I'd put it with the rocks?

Interviewer: Why?

Curt: Well, it's not exactly like a mineral. If you take a close look at it with the magnifying glass you can see it's sort of like a rock inside. Well, I could put it with the minerals cause it's like-also kinda like a mineral inside.

Interviewer: What's the difference? You're not quite sure about that?

Curt: Me either (not sure) but you can sort of tell by looking.

Interviewer: Maybe you can show me another mineral.

Curt: This yellow one (Sulfur) here is I think a mineral, but number 10 (brick) I'm not sure if it's a mineral or not-- I think it's a mineral.

Interviewer: What did you call that before?

Curt: Brick?

Interviewer: Do you think brick is a mineral?

Curt: Well, kind of a mineral and this one (halite) like glass. I think it's probably a mineral. I wonder if it's a bit slippery like ice? Nope.

Interviewer: Any other minerals in the pile?

Curt: Well, there is this white rock here (80-dolomite) that is a mineral.

Interviewer: Is this shiny gold (pyrite) one you liked a mineral?

Curt: Yup.

Interviewer: And what about this one (lead)?

Curt: I think this is a mineral too.

Interviewer: And the black one you like-is it a mineral?

Curt: I think so.

Interviewer: Lets put the minerals in one pile.

Curt: How about if we put the minerals here and all the non-minerals in another pile. I think I'll put this (brick) in the non-mineral pile. (changes he mind) [Classifying]

Interviewer: And 125 (black/white layered pebble)?

Curt: Well, I don't know -kinda like a rock and kinda like a mineral. We could split this (can't split it).

Interviewer: And 12 (concrete)?

Curt: I think that's cement. It kinda looks like cement and it's got some rocks in it and some wee, wee rocks.

Interviewer: Would it go in the mineral pile or the rock pile?

Curt: The rock pile.

Interviewer: So cement's a rock?

Curt: Well, not exactly a rock.

Interviewer: Why not?

Curt: Well, you don't really pick up cement from the ground like regular rocks and sometimes throw it and stuff. [Experience]

Interviewer: Do you think cement is made the same way regular rocks are made?

Curt: Nope.

Interviewer: How are they different?

Curt: Well, it's mixed with things and it dries kinda more-it gets hard faster than rock.

Interviewer: And rock takes a longer time?

Curt: Yes

Interviewer: How much longer?

Curt: A few years maybe.

Interviewer: I see. Look at 82 (shist).

Curt: This one's kinda neat like smooth, kinda glassy stuff.

Interviewer: How does it feel?

Curt: Kinda bumpy and glassy. Hey, maybe somebody put some stuff in it. You know - what was it again? The stuff that makes things shine?

Interviewer: I'm not sure what it is--do you spray it on or paint it on?

Curt: Well, you cculd put it on an old brush.

Interviewer: Varnish?

Curt: No, not varnish.

Interviewer: Can you think of something that would have it on?

Curt: Well, I know, I got it right under my nose but I just can't remember the name.

Interviewer: Well maybe it will come to you later. Look at 37 (shale).

Curt: Kinda like coal except it' not black. I like this thing -it looks like a rock, but it's a mineral (130-large cream pebble with holes).

Interviewer: Why is it a mineral?

Curt: It's got all these different colours and stuff and it's also smooth. White rocks don't usually have that. Rocks don't really feel like this either. Say maybe we could crack this open. [Color criterion, malleability]

Interviewer: Any other ones that you want to look at?

Curt: No, 14 (brick) looks sort of like a brick. Hey, maybe we can break it. Want to see what it looks like on the inside? (breaks it) Hey, it is kinda white in there.

Interviewer: I think that's where I hit it. Here's a better piece. Look at the inside. Is it the same?

Curt: Sort of. What's this thing?

Interviewer: A steak plate.

Curt: This thing (magnet)?

Interviewer: What do you think it is?

Curt: A magnet.

Interviewer: Do you think rocks are magnetic?

Curt: I don't know. Hey, this one (lead) isn't. This one is.

Interviewer: Any idea what is in that rock?

Curt: Nope. Hey, coal is a bit magnetic (slate-38).

Interviewer: Any others?

Curt: Here's one. Hey let's make a pile of all magnetic rocks. [Magnetic criterion].

Interviewer: What would we do with all these others then?

Curt: Leave them.

Interviewer: And what would we call them?

Curt: Non-magnetic minerals. Hey, this is a funny kind of rock (51-granite).

Interviewer: What's interesting about it?

Curt: Hey, these magnets push each other apart (plays with magnet).

Interviewer: You made a group of minerals and non-minerals and magnetic and non-magnetic minerals. Can you think of any other way of making some groupings?

Curt: Well, I could make some groups of clearish ones (gypsum, calcite, halite). [Transparent criterion]

Interviewer: What about the rest?

Curt: We could make a pile of all the shiny ones. [Shiny criterion]

Interviewer: All right. Which ones would belong to it? (83.23,91, shist). Can you think of another way of grouping them?

Curt: Whitish ones.

Interviewer: Would you put 40, 41 (halite,) in the white pile? [Colour criterion]

Curt: Well, I'd put 41 in the white but I think 40 would go---it's not exactly whitish.

Interviewer: Can you think of another way other than white?

Curt: Some would go in the middle-sized pile and some in the small pile. [Size criterion]

Interviewer: Can you think of another way other than size?

Curt: Colour.

Interviewer: Did you use colour already?

Curt: I used white. I could use other colours--brown.

Interviewer: Another way other than colour?

Curt: I don't know--that's about it.

FOSSILS

Interviewer: Let's look at this other pile of objects.

Curt: Hey, this (snail) is a neat object.

Interviewer: What do you think that is?

Curt: Probably a carved rock. [Human intervention]

Interviewer: Does it remind you of anything?

Curt: A shell--a heavy shell.

Interviewer: Is it a rock?

Curt: I think so and I think some of these are fossils. Yup here's one (35-plaster cast).

Interviewer: How can you tell it's a fossil?

Curt: Well, it's the dug-in of a shell.

Interviewer: How do you think that shell got in there?

Curt: Well, maybe--I don't know what this came from but maybe it went into the middle of the substance of whatever it is. And then maybe something got in it and it dried. Now this (coral) is an interesting object. Like a bunch of buildings with a lot of balconies. [Curt lives in high-rise - experience?]

Interviewer: Any idea what it is?

Curt: Nope. I find some of these fossils interesting, like 166 (trilobite).

Interviewer: What do you think that one is?

Curt: A fish. Probably a little small fish but I wonder why it's all bumped up.

Interviewer: Any idea how that happened?

Curt: Nope.

Interviewer: Where do you think it was formed?

Curt: Maybe in a place like on the beach of a river.

Interviewer: What makes you say that?

Curt: Well, the mud would have gotten all out of shape if it were way under water. Like maybe kinda close to a bank and it could have dried somehow -probably from the mud.

Interviewer: Which part do you think used to be mud?

Curt: This part on the inside.

Interviewer: What do you think the stuff on the outside was?

Curt: Maybe a bit of mud too.

Interviewer: Take a look at this one (graptolite).

Curt: Kind of like a long thing with hair.

Interviewer: What do you think it is?

Curt: I don't know.

Interviewer: Ever see anything like that around here?

Curt: No.

Interviewer: Take a look at 167 (fern).

Curt: Looks like it's a fossil from a leaf.

Interviewer: How do you think it was formed?

Curt: Maybe it fell down on some mud around a tree -- would have been a weak branch.

Interviewer: Where did it fall?

Curt: Probably off the tree into some mud and made a print. And maybe the wind blew it away before it dried in there.

Interviewer: Do you think this leaf could have been formed in the same area as some of these other fossils?

Curt: Maybe.

Interviewer: Which ones might have been formed near each other?

Curt: This one it could have been formed in a shallow bank and the tree here and the mud could've been near the shallow bank --in fact there could have been dirt, and the water might have come up pretty high and made the dirt into mud.

Interviewer: Look a these (27, 29-barnacles).

Curt: A bunch of little things popping up-like peanuts.

Interviewer: How do you think they got on there?

Curt: I don't know.

Interviewer: What's this stuff here?

Curt: Just a plain rock.

Interviewer: Did you look at this one (large brachiopod).

Curt: Like a flying sub.

Interviewer: And 2(clam)?

Curt: It's kinda like a fossil

Interviewer: A fossil of what?

Curt: I don't know. It looks like it has radio waves on it, and it also reminds me of this thing (snail). 32 (horn coral) looks kinda lika a cork.

Interviewer: And 102 (spiral snail shell)?

Curt: That reminds me of a shell too.

Interviewer: And 5 (brachiopod)?

Curt: Reminds me of a fossil of a bone and I wonder what 105 (half horn coral) is - reminds me of part of a back bone of a fossil.

Interviewer: And 30 (long narrow brachiopod)?

Curt: Reminds me of a small verison of a sea shell. I wonder if any of these are magnetic (tries them all). Oh, I didn't see this big one. Maybe this is a rock--it's rocky here.

Interviewer: Look at 23 -(petrified wood). Ever see anything like it before?

Curt: Nope, It's not magnetic.

Interviewer: Do you think all of these objects are fossils?

Curt: Nope.

Interviewer: Which ones aren't?

Curt: Some of these stones (brachiopods) here don't seem like fossils.

Interviewer: Do you think you could put these in groups for me?

Curt: Well, I could put them into big and small and also in fossil and non-fossil. [Size criterion]

Interviewer: Can you show me the ones which would be fossils?

Curt: Well, I can pick out some of them that would be fossils. One of them (15-red, coarl) looks like noddle soup.

Interviewer: Look at 7 (red coral).

Curt: Looks like some of the moon. Looks like they put little steel things in.

Interviewer: Do you think it's a fossil?

Curt: I don't know. Here's another fossil (19 graptolite).

Interviewer: Do you think this (the lines) is a fossil?

Curt: That might be a scratch - let me look at it with the magnifying glass. Yup.

Interviewer: Can you think of another way of grouping besides fossil and non fossil?

Curt: Size - small, super small, big. [Size criterion]

Interviewer: Any other way?

Curt: Here's one (6) that looks kinda like the moon. How about all the black ones?

Interviewer: Yes - look at what I'm doing. Can you add to my group (shells)?

Curt: Yes - this one has lines, this is lines.

Interviewer: Look at this one.

Curt: No lines.

Interviewer: Do you think lines is what makes them belong? Is there something else?

Curt: Something else?

Interviewer: I'll keep putting more in the group.

Curt: Let me just check ---they all remind me of shells.

Interviewer: Can you find others that would fit? What kind
of a shell does it remind you of?

Curt: A clam shell.

Interviewer: Are there any questions you'd like to have
answered about rocks or fossils?

Curt: How the things get out of fossils and how some
of them were made- like some of them probably
weren't just made by mud- but other thigs too.

Interviewer: What about rocks?

Curt: What their names are. What makes them sparkle
and magnetic and stuff.

Interviewer: Would you like to know where they came from and
how they were formed?

Curt: Yes.

June 16, 1976

T2/1

David (10 years 6 months - completed grade 5)

David: This one's brick.

Interviewer: How can you tell?

David: By the color and texture. A normal rock isn't like this - how smooth it is. This is mica.

Interviewer: What is mica?

David: I don't really know but it's used in windows sometimes. I don't know where it comes from but we found some stuck in some quartz. [Direct experience]

Interviewer: Have you ever seen it by itself before?

David: By itself? Once before we found a bit, but it wasn't clear.

David: This one is pyrite.

Interviewer: What does that mean?

David: It's fool's gold - it's so gold that guys used to think it was real gold.

Interviewer: Do you know where it's found?

David: What do you mean?

Interviewer: Well, where do they get it from?

David: Under the ground?

Interviewer: How does it form?

David: I know it's some kind of copper ore---

Interviewer: That it's found near?-

David: Yah, I think so, cause, like some shiny rocks have copper in them.

Interviewer: That's similar to this one, is it?

David: Yah, kind of more of a reddish colour though.

Interviewer: Look at 127 (Conglomerate).

David: It's concretion for one thing. Looks awfully man-made to me.

Interviewer: What makes you say that?

David: Well, sort of the differences in the rocks; it seems so smooth.

Interviewer: What could have caused that?

David: Could have been in water.

Interviewer: How does water make it smooth?

David: It just runs over it and wears it away.

David: Sort of looks like it - so dark and so lightish. [Colour criterion]

Interviewer: You don't think that you'd find that naturally?

David: I don't know - maybe you could, I haven't seen a rock like that.
This is sandstone (118-Small black pebble).

Interviewer: How can you tell that?

David: It's so smooth, a single color and you can almost see the sand in it. This is quartz. I know one place you can find it-somewhere in the U.S.-in Montana somewhere.

Interviewer: Any idea how it formed?

David: From heat like a volcano.

Interviewer: What would the heat have to do with it?

David: Well, it melts all the rocks and they all form together like that.

Interviewer: Do you like this one?

David: Yes, the color- its almost transparent. They say it's supposed to be clearer than glass.

Interviewer: Rose quartz or any quartz?

David: White quartz is just normal.

Interviewer: Do you know what quartz is made of? Did you ever read about it?

David: I've read about sandstone, but not quartz.

Interviewer: What did you read about sandstone?

David: Well like - it's sort of like a whole bunch of sand is down packing it together and maybe - I don't really how-how deep until it's heavy enough to pack it all togehter with water and everything until you get that.

Interviewer: Does it take a long time?

David: Yah.

Interviewer: How long?

David: More than 10 years - I don't really know. I can't remember if it's more than a 100 or not. [Time concept]

Interviewer: I see. Any other sandstone here?

David: Oh yah, this looks like big chunks of sand (114-Small conglomerate).

Interviewer: And 33 (Obsidian)?

David: Let me see, it's transparent. No. We got something like that - it's called obsidian or something.

Interviewer: Do you know how it it's formed?

David: Volcano or something.

Interviewer: What happened?

David: Sort of like melts sand, sort of glass kind of stuff.

Interviewer: What part of the volcano do you think it's found in?

David: The hot middle part.

Interviewer: Down deep?

David: Way down deep.

Interviewer: Does it take a long or short time to form?

David: Short I think. Because it so hot, like 2000 degres or higher. I think that would be enough to melt sand.

Interviewer: And 12 (Concrete)?

David: Concrete.

Interviewer: How can you tell that?

David: If you look at the sidewalk, it's the same colour. This stuff is so much of a different colour - I just sort of guessed it.

Interviewer: Any others you find interesting?

David: 122 (Conglomerate) is sort of a concretion thing.

Interviewer: What makes you say that?

David: You can see a whole bunch of different rocks cemented together.

Interviewer: What would be the thing that cements them together?

David: A kind of natural cement - like sand and water.

Interviewer: How would those little stones get caught up in there?

David: They might be somewhere in the dirt or by the beach and they just do this.

Interviewer: Look at 48 (Pumice).

David: Awfully light. I've never seen anything like that.

Interviewer: Any idea what would makes that? Think it's a rock?

David: Is that asbestos?

Interviewer: I don't think so.

David: I didn't think so, but it looks a bit like it.

Interviewer: How can you tell asbestos? Is it sort of special?

David: It's fireproof- soaked under super temperatures.

Interviewer: Would the particles look the same in asbestos?

David: Well, there would be fibers sticking out. This- I don't know what it is though.

Interviewer: What about 71 (Sandstone)?

David: It seems that there is sand in it. Smells a little salty.

Interviewer: Would it have salt in it?

David: It looks a bit like it - sort of grains in it.

Interviewer: How could you tell if there were salt in it?

David: Taste it.

Interviewer: Want to taste it? (Does so.)

David: It's not salty

Interviewer: Not salt then?

David: Quartz - tiny little pieces.

Interviewer: How come you get some small pieces and others are so big?

David: They get all pounded up.

Interviewer: How would it get pounded up like this - while in this case you get such large pieces?

David: Well, this was found in a much different place, maybe deep deep down in the earth where there was enough pressure to crack it all up.

Interviewer: Do you think 71 would be down deeper than 66? (sandstone vs porphyry)

David: This almost looks like it has asphalt in it--------.

Interviewer: So you think it might be formed farther up?

David: Well, maybe in between. I don't know why, but I think it might be inbetween.

Interviewer: Look at 37 (Shale).

David: On --slate.

Interviewer: What is slate?

David: You make blackboards out of it and I can tell because slate falls off in slabs sort of.

Interviewer: Is that the colour of slate?

David: I've always seen sort of darker places.

Interviewer: 38 (Slate) is a dark one?

David: That looks like slate too.

Interviewer: Can slate be different colours then?

David: Yah. This one's more green.

Interviewer: And 78 (Red slate)?

David: Seems almost like slate too.

Interviewer: In what way?

David: It has sort of lines.

Interviewer: How come this would have lines? Does 38 (Slate) have lines?

David: No- I still think it's sort of like slate cause it's smooth and partly it's a dark color.

Interviewer: How does slate get formed?

David: Not sure, I think it's made out of sort of like sand, packed together - on both sides really hard.

Interviewer: If it had sand in it, would you see some of the grains?

David: Maybe it's packed in so well you can't see it.

Interviewer: Very close together?

David: Yes

Interviewer: If you could choose five rocks for your collection which five would you take?

David: This - like halite (40-Halite).

Interviewer: What's halite?

David: It's a lot like quartz. I don't know really what it is - I've seen pictures of it. In pictures it always seemed to be in a cube -an octogon shape.

Interviewer: How do you think it got to be that shape?

David: I think that's the way it's formed - sort of like a crystal.

Interviewer: What's a crystal?

David: A lot like salt.

Interviewer: Salt is a crystal?

David: I think so.

Interviewer: How would one recogninze a crystal? If you were trying to explain to me what a crystal was, what would you tell me to look for?

David: Like giant piece of salt.

Interviewer: And what in particular would I think about? What would I see?

David: Kind of a clear cube.[Transparent criterion]

Interviewer: So it has a shape to it?

David: Yah.

Interviewer: Any other crystals in here?

David: Is this (brown pebble - agate-like) topaz by any chance?

Interviewer: Im not sure about that one actually.

David: It sort of looks like it.

Interviewer: Is that a crystal?

David: Seems like glass almost. Well, it looks like a crystal, it's so clear. The color looks like topaz, the shape's like a crystal.

Interviewer: Is that a cube?

David: Well it's more of an octogon.

Interviewer: So crystals can be different shapes?

David: Yah, it's sort of oily.

Interviewer: What's that sticking out?

David: That- you often find - oh, now I remember how crystals are formed. Like water running over something or dripping down leaving these minerals behind. [Book learning]

Interviewer: What's a mineral?

David: I'm not sure but I think it makes a crystal.

Interviewer: Go on-------.

David: It drips down the minerals first and sort of grew up and broke off there.

Interviewer: When you say grew up - what do you mean?

David: Kinda like the water came down and splashed on there and left the minerals behind and more water and more water, and sort of got a pile of minerals and just sitting there like that. Or maybe it was the other way around. Looks like it got another piece on top of it.

Interviewer: I see. Any other crystals here?

David: (Picks up sulfur and smells it). This is sulfur, yes?

Interviewer: Are there any crystal in that?

David: It's kind of soft --it smells stronger if it's hot. Where we were at the hot springs it smelled stronger. Looks like some sort of crystals in there. [Experience]

Interviewer: How would you describe the little crystals in there?

David: Sort of yellowish.

Interviewer: Any shape?

David: Some seem to be long straws and the middle seems to be bits of cubes. There doesn't seem to be a uniform shape. Now some other rocks that I'd like ..... halite, 40, S, boat, oh - that glass looks almost like an amethyst. Looks almost blue and I see through it. And I (lead) looks sort of like a metal. [Criterion]

Interviewer: How would you know it's a metal?

David: Heat it up hot, and if it were metal it (the rock) would just kind of stay solid cause it would have to be a high temperature and metal would kind of drip out. [Melting criterion]

Interviewer: Some minerals or substances come out a lower temperatures?

David: This looks like iron.

✓ Interview: How could we find out if it's iron?

David: It's heavy.

Interviewer: Is everthing that's heavy iron?

David: Well, no.

Interviewer: Can you think of anything else we could do?

David: Put a magnet on it.

Interviewer: Let's see if we have iron in it?

David: Yah - it's iron.

Interviewer: How do you know?

David: Because you have a magnet.

Interviewer: Not necessarily. I carry a number of different things with me only I don't bring them out unless someone asks for them.

David: Oh. (Tests with magnet) It's iron, I think, or it could be steel, but steel is made from iron and this still has rock in it. It's iron, I think.

Interviewer: Any more iron around here?

David: Mind if I use the magnet?

Interviewer: Oh no, go ahead.

David: Is this iron? Is this a magnet? I've seen something like that-sort of like just a magnet.

Interviewer: You mean the rock itself is a magnet?

David: Yah - probably.

Interviewer: How would you tell it were a magnet?

David: No, I think it's iron - just little bits of iron all flaked up this time.

Interviewer: Why do you say that?

David: Cause it sticks.

Interviewer: Why do you think they're all little bits? (83-Mica shist)

David: Maybe this one's been heated up slightly and all formed together and wasn't hot enough to drip out. Or maybe that one was pushed together super hard and and this one wasn't.

Interviewer: Any other iron ones?

David: Guess not. (Finishes testing) Nothing else looks like iron. [Criterion changes]

Interviewer: What does iron look like?

David: Kind of like shiny. I'd bring a metal detector or this magnet.

Interviewer: You have three rocks now--which others would you choose?

David: This one-(iron)-cause I've never actually seen a piece of iron before and - what's this (5-Mica)?

Interviewer: Take a look and see if you can figure it out.

David: Looks like mica again.

Interviewer: Why do you say that?

David: Well the thinness, the weight, and not the colour, but the texture. They both have finger prints on them; both shiny.

Interviewer: Do you think mica comes in different colores?

David: Yes. Boy, that's heavy. Is this (lead) a metal?

Interviewer: What makes you think it's a metal?

David: The colour.

Interviewer: What about the colour makes you this it's a metal?

David: Like it's so shiny.

Interviewer: Does that have crystals in it?

David: No - sort of like cubes. [Criterion change]

Interviewer: You told me cubes were crystals. [Clearness is crystal?]

David: Well, not all cubes.

Interviewer: Oh.

David: You can sort of see they stick up a little bit. I've seen something like this in school once. It's really heavy and really easy to break. Somebody dropped it and it shattered into all kinds of little cubes. [Cleavage criterion]

Interviewer: So this has cubes in it?

David: I think so.

Interviewer: Which is your fifth choice? What number is that? 82? (takes shist)

David: Looks a bit like quartz to me. It's hard and not soft like that other one-wherever it went. This one feels smooth and is sort of made in layers but I don't know what it is. A lot of these look like quartz but probably they're not. ..... Now, I'd probably take this one (lead).

Interviewer: What makes you like that one?

David: The colour. It splits up into little cubes.

Interviewer: If you were going to make some groups of rocks that are alike, how would you do it? What groups are you making now?

David: All the man-made sort of things (takes 127-

David: They're fossils. Is this actually a fossil (35-plaster cast)?

Interviewer: Do you think they're all fossils?

David: This one's not - it looks like a clam shell stuck in plaster. This one (32-horn coral) has a sort of tail and 11 (meristella) looks like calcium. I guess not (tests with HCL). I think this one was formed in the water, not on the surface or it would have ripples. This one is a clam or something ..... sand would fill up the holes and after a long time it would turn to rock.

Interviewer: How do you think 167 (fern) was formed?

David: When this stuff was mud this plant was pressed into it and later while the mud was starting to harden and the plant just rotted away and turned to rock.

Interviewer: How about 1850 (graptolite)? Is that a fossil?

David: This has just been written on it -- let's try that stuff out (HCl). It's got that stuff in it and a lot of others do to. I think it's a fossil. What happens if you put that stuff on a pencil mark? Let's try 19 (graptolite). It has a pencil mark.

Interviewer: Anything happening?

David: Not much - it still could be a pencil mark but I don't think it is. It's too fine to draw with a pencil.

Interviewer: How about this one (other graptolite)?

David: I think that one is a pencil mark because it's so circular.

Interviewer: What about 15 (coral-red)?

David: I think that's a fossil also.

Interviewer: From where?

David: I don't know.

Interviewer: And 27 (barnacle)?

David: Looks like a geode.

Interviewer: What's a geode?

David: It's sort of like a ball of any old kind of rock with crystals inside.

Interviewer: How do they get in there?

David: The crystals formed first and then they turned to rock or else it's the other way around. I don't really know.

Interviewer: Do you think that's a fossil?

David: No.

Interviewer: What about 25 (rock with shells)?

David: Yes, clammy sort of thing.

Interviewer: If you were going to group them - how would you do it?

David: Like this (sorts) -- This (plaster cast) would go by itself because it's phony.

Interviewer: Why do those go together?

David: Because they're done sort of one way (166-trilobite, 167-fern; graptolite; 11-meristella; 29 and 27-barnacles).

David: Those are my groups.

Interviewer: What made you put 32 and 105 (horn corals) together?

David: They're almost the same shape and this is only a half a tube.

Interviewer: How come these (snails) were placed together?

David: They're all sort of the same type - large, medium and small.

Interviewer: And 7 (coral)?

David: Goes with 4 (brachiopod), 7 and 15 (round corals)-I'll put 7 and 15 off on their own. And 125 - I don't think it's a fossil

Interviewer: Are fossils ever formed on land?

David: Yah - plants could be formed on land.

Interviewer: If I took a piece of rock (hard) - do you think it could become a fossil?

David: No, because it wouldn' make a print on it.

Interviewer: What conditions would you need?

David: Mud.

Interviewer: Some wet stuff?

David: Yah, I guess so.

Interviewer: Do you think fossils could form in mountains?

David: Well, no, not unless there was water - a swampy area.

Interviewer: Could fossils ever from around volcanoes?

David: No, because it's too dry.

Interviewer: What if some of the liquid stuff ran out down the mountains and covered some things up. Do you think they could be preserved?

David: I guess so if you did it that way, but it might be blurry. Lava is usually a quick process so you wouldn't get much of an imprint.

Interviewer: Any questions about fossils?

David: None. Do most people find rocks or fossils easier?

Interviewer: Fossils, I guess.

David: Same way with me.

Interviewer: How come?

David: They're sort of different - you can sort of tell what they used to be and rocks you can't see what's in them and fossils you can.

Interviewer: Supposing I put all these together. What is the basis of my grouping?

David: These are the same kind of rock (166, 167, graptolite, trilobite, fern). These are flat formed. These are formed differently. There was a _____ smashed between rocks. This one was a clam packed in mud, rotted away and turned to rock.

Interviewer: Any other reason I would group these?

David: Different shapes - flat and that's about all I can think of.

June 26, 1976

T3/1

Paul (15 years - completed 9)

Interviewer: Examine this collection and then we'll talk about some of the different objects. (Paul works silently - doesn't comment.) Are any of these interesting to you?

Paul: I suppose the transparent ones.

Interviewer: Have you ever studied about rocks?

Paul: In ninth grade.

Interviewer: Did you study it all year?

Paul: No, it was mostly weather and stuff like that.

Interviewer: Did you do much with rocks?

Paul: No.

Interviewer: Look at this one (Lead). How would you describe it?

Paul: Metallic.

Interviewer: Why metallic?

Paul: The shine.

Interviewer: Any idea what that would be?

Paul: An ore or something.

Interviewer: What's an ore?

Paul: A mineral or something containing a metal that's profitably extracted.

Interviewer: And 8 (Pyrite)?

Paul: Fool's gold.

Interviewer: Is it a rock?

Paul: A mixture.

Interviewer: Of what?

Paul: Iron pyrite.

Interviewer: And 127 (Large red pebble)?

Paul: Could be a marble or granite - different kinds of stones in it.

Interviewer: How did it get to be that shape?

Paul: Weathered, worn down.

Interviewer: By what?

Paul: Water, wind.

Interviewer: And 33 (Obsidian)?

Paul: Flint

Interviewer: And 7?

Paul: No.

Interviewer: And 66 (Porphyry)?

Paul: Another mixture.

Interviewer: How do you think the white things got in there?

Paul: Probably some loose gravel and mud compacted.

Interviewer: Any other way rocks are formed besides compaction?

Paul: Igneous rocks.

Interviewer: How do they form?

Paul: Heat.

Interviewer: What does heat have to do with it?

Paul: Well, melts it and then solidifies it again and crystalizes.

Interviewer: Do you think there are any igneous rocks in here?

Paul: Granite, (picks up 136-Rose quartz), Marble (80-Dolomite), and 127 (Large pebble).

Interviewer: How can you tell if it's igneous or not by looking at it?

Paul: Structure, if it's crystal or not.

Interviewer: What's a crystal? How do you know when something's a crystal or not?

Paul: Geometric pattern.

Interviewer: Any other crystal in here besides these two?

Paul: There's one (82-Talc shist) might be.

Interviewer: What's the geometric pattern there?

Paul: Um--- hard to say.

Interviewer: How would you describe the texture?

Paul: Oily, slippery.

Interviewer: Any others that might be crystals?

Paul: This one (40-Halite) for sure and 41 may be quartz or something. 136 (Rose quartz), 80 (Dolormite), 40 (Halite) - would be crystals for sure.

Interviewer: Let's go back to 66 (Prophyry). Could it be formed deep in the earth? Could those white things be crystals?

Paul: Might be.

Interviewer: Could you think of how that might happen---- (Pause) If it's in the earth would it be a liquid?

Paul: Yah.

Interviewer: Many liquids? (Paul nods) How would it come to pass that we end up with this... (Pause) How would you get the crystal out of the liquid?

Paul: Cool down.

Interviewer: Would these both cool at the same rate?

Paul: The white stuff probably cooled slower than the dark stuff.

Interviewer: What makes you say that?

Paul: Well, the slower the things cools, the larger the crystals.

Interviewer: How would you describe 120 (Red/white layered pebble)?

Paul: Sandstone or something.

Interviewer: How did the layers get on there?

Paul: The sand that was compressed, the layers built up gradually.

Interviewer: And this piece (Iron)?

Paul: Iron ore.

Interviewer: How would you test to see if it were iron?

Paul: Magnetic.

Interviewer: Maybe you'd like to use this magnet (he tests it).

Paul: Yah, it is. (attracts)

Interviewer: Do you think this (Lead) is iron?

Paul: No, because the lines of cleavage are different.

Interviewer: What's a cleavage line?

Paul: The way-----if pressure were exerted it would split along here rather than any place else.

Interviewer: Are those crystal in there?

Paul: No.

Interviewer: Why not?

Paul: No real definite shape to all of them (tests 8-Pyrite) nothing.. a little bit maybe.

Interviewer: And 14 (Brick), ever see anything like that one?

Paul: A piece of broken pottery or something.

Interviewer: How can you tell?

Paul: The red specks of clay in there.

Interviewer: Is that a rock?

Paul: Not really.

Interviewer: What makes something a rock? How do you know if it's a rock or not?

Paul: The way they're formed and what they're made of?

Interviewer: What do you mean the way they're formed?

Paul: Well, sedimentary rocks are compressed sand and igneous rocks are heated and crystallized, and this could be sedimentary.

Interviewer: But, if it were a brick, you said it wouldn't be be a rock.

Paul: That would be clay -- sort of like soil.

Interviewer: And 122 (Small conglomerate)?

Paul: Igneous rock maybe or the pieces would have been cemented together by something?

Interviewer: Do you have the cementing process when you have igneous rocks?

Paul: Not for-like-one mess of rocks, but if you have a bunch of gravel covered by mud and stuff.

Interviewer: Is that igneous?

Paul: That's sedimentary---The mud being compressed and everything.

Interviewer: If I asked you to pick out the five rocks that are most interesting to you, which five would you pick?

Paul: This one (8), (136), Boat, 33 and 124 (Pyrite, Rose quartz, boat, Obsidian, Brown agate).

Interviewer: Why would you choose 124 (Brown agate)?

Paul: Colour

Interviewer: Any other reason?

Paul: Favoritism

Interviewer: And 33 (Obsidian)?

Paul: Useful.

Interviewer: And this (Boat)?

Paul: Curosity.

Interviewer: And 136 (Rose quartz)?

Paul: Nice looking.

Interviewer: What's nice about it?

Paul: Colour and texture.

Interviewer: And 8 (Pyrite)?

Paul: Well, fool's gold.

Interviewer: If it were Iron pyrite, how could you tell?

Paul: Heat it, and it would be a bad smell.

Interviewer: Would it be attracted to a magnet?

Paul: Only slightly.

Interviewer: Try it and see.

Paul: Nothing.

Interviewer: Does it suprise you?

Paul: No, it was expected.

Interviewer: But, doesn't it have iron in it?

Paul: Only a little.

Interviewer: Smell it.

Paul: Doesn't smell like anything.

Interviewer: Could you form some groups using these rocks? Form only one group at a time.

Paul: Igneous, sedimentary and metamorphic.
Igneous = 84(Gneiss), 124(Brown agate), 136(Rose quartz), 79(Limestone), 127(Pebble), 51 Granite(Biotite), 80(Dolomite), 71(Sandstone), 126 Black/red layered pebble, 76(Quartzite).

Interviewer: Do all igneous rocks have crystals?

Paul: Yes.

Interviewer: Where are the crystals in 84 (Gneiss)?

Paul: Cooled off quick so they're extremely small.
Sedimentary = 120(Red,white layered pebble), 37(Shale), 38(Slate), 78(Slate), 93(Chalk), 33(Obsidian), 74(Shale), 48(Pumice).
Metamorphic = 125(Brown green layered), 110(Small,white pebble), 118(Black pebble), 111(Striped pebble), 114(Small conglomerate), 64(Basalt), 82(Talc), 121 maybe - (Large white rock).

Interviewer: Why not?

Paul: Doesn't have grainy feeling. 112(round red pebble).

Interviewer: And 12 (Concrete)?

Paul: Cement or slate or something. This is a mixture so you would hardly call it anything.

Interviewer: What's it a mixture of?

Paul: Cement, gravel limestone.

Interviewer: Is it a rock?

Paul: No.
Could be the same thing as that --different proportions of the mixture. Same for this one (11-Concrete) --unless you wanted to classify two different elements of it.

Interviewer: It's not a rock either?

Paul: No.

Interviewer: So, this is the pile of mixtures?

Paul: Yes. 122 (Small conglomerate) would be a mixture of igneous and sedimentary, and 78 (Slate-red) would be metamorphic because there's no grainy feeling.
121----(Big white rock) metamorphic maybe. Hard to say about the rest of them. This one (40-Halite) would be a mineral.

Interviewer: What is a mineral?

Paul: Close to a pure element (40-Halite, 83-Mica Schist, 8-Pyrite, Iron, Lead). These would be pieces of mixtures that you really couldn't count as rocks (122, Conglomerate and brick) This is an ore (122 - Schist). I wouldn't have any idea of these (3, boat, Iron, 41 and Schist).

Interviewer: Can you think of any other ways of grouping than these categories?

Paul: Well, by density-----but then it would come out pretty much the same though.

Interviewer: Any other ways?

Paul: Texture, hardness.

Interviewer: How would you figure out the hardness?

Paul: Well, there's a scale. Colour, -- that's about all.

FOSSILS

Interviewer: Take a look at this other collection.

Paul: Fossils.

Interviewer: Does that one (24-snail) remind you of anything?

Paul: A snail or something.

Interviewer: Think that's a fossil?

Paul: It would be the acutal body of the petrified, like petrified.

Interviewer: Would it be a fossil?

Paul: Yah, because it's an impression of a thing of the past. 5 would be a fossil and 35 (plaster cast).

Interviewer: What's that (35) a fossil of?

Paul: A scallop or something - looks like it was just made --- straight edge there and papery on the bottom - plaster of paris.

Interviewer: Is it a fossil?

Paul: Not a true one, but you could call it one.

Interviewer: Why isn't it a true fossil?

Paul: Just made.

Interviewer: Fossils have to be something that weren't just made?

Paul: It was maybe made by a person.

Interviewer: And real fossils aren't?

Paul: No. And 27 (barnacle) is not a fossil ----a barnacle --just animals that grew on there. Same for 29 (barnacle). And 16 (coral) is petrified wood----has sort of the structure of wood only the pores are kind of open.

Interviewer: And 23 (petrified wood)?

Paul: Just a rock. 25 are shells embedded in sedimentary rocks.

Interviewer: And 7 (coral)?

Paul: Some fossilized rock.

Interviewer: Any ideas of the conditions under which this was formed?

Paul: Plants or whatever they were---were covered and then compressed.

Interviewer: Was it formed in the sea or on land?

Paul: Hard to say....probably sea (groups automatically).
Fossils = 166(trilobite), 167(fern), 30(long, narrow brachiopod), 32(horn coral), 24(ammonite), 102(small spiral shell).
Formed like rock = 10(small white brachiopod), 13(declama), 4(brachipod), 11(meristella).
This (grapolite-18) could be a fossil or just a wear mark of some kind and this (19-Other graptolite) would be a fossil ---some grass or worm 10, 13(rounded rocks). Hard to say what the rest of these are (32 & 105-horn corals),

23 (petrified wood).

Interviewer: These are non-fossils here?

Paul: These (35,135) would be fossils embedded in rock.

Interviewer: So you have grouped them into fossils and non-fossils. Is there another way of grouping them?

Paul: Plant or animal.

Interviewer: I see, another?

Paul: If you could get an age on them or you could get the impressions or the actual fossilized body of it.

Interviewer: Have you ever collected rocks or fossils?

Paul: No.

Interviewer: Did you ever do anything like this in school?

Paul: Back in 5th grade we classified rocks.

Interviewer: Did you do this last year?

Paul: Only a little.

Interviewer: What's the process under which fossils are fromed?

Paul: Well you --the plant or animal comes to rest in some mud and- or something and the material around into sedimentary rock.

Interviewer: How does the sedimentary rock process take place?

Paul: The sand or mud keeps building up and gets compressed.

Interviewer: What's the time involved?

Paul: Millions of years.

August 3, 1976

APPENDIX D

Teacher's Guide for Minerals and Rocks Unit

FOREWORD

"One must learn
By doing the thing: for though you
think you know it
You have no certainty until you try."

These words of Sophocles indicate where the emphasis is placed in Division II Science--on doing. A series of units have been prepared each containing a number of activities specifically designed to afford the student the opportunity to master a quite definite set of objectives. Student participation is the key. Each student should be encouraged through handling materials, recording and discussing observations, making inferences and analyzing results to gain an understanding of some of the basic ideas of science as well as further developing the skills or processes used in science. Every attempt has been made to assist the teacher in this task by stating precisely the objectives each activity attempts to facilitate, the particular materials required for each activity, suggestions for instruction, providing transparency masters and appropriate students sheets with corresponding teacher keys. It must be emphasized that the "answers" provided are not to be taken as inviolate but are merely what might be considered typical student responses. Different answers given by students might well be just as "correct" and should be evaluated by the teacher in the context of the teaching situation. Provision of student sheets hopefully will not deter teachers from encouraging students to record findings in their own words in their science notebooks.

INTRODUCTION

Over 2,000 minerals have been identified though many of them such as emeralds and gold are rare. About 40 minerals are common enough to be called rock--forming minerals while only 10 of these are in such abundance as to make up more than 90 percent of the weight of the earth's crust.

The study of minerals is, therefore, essential to the geologist because rocks are masses or "aggregates" of crystals. The field geologist or the prospector will know some simple tests which will help him to classify and identify minerals and to determine the origin of the rock formed by minerals.

In Section A of this unit, the students will gather data about the physical properties of some common minerals and interpret these data to identify the mineral. Finally in Section B some common rocks will be examined to determine their mineral composition.

For most of these activities one set of mineral chips of the three purchased should be used as a reference set only. The enclosed Identification Table will be most useful. The teachers should obtain a copy of "Rocks and Minerals" by Arem Joel (see page 21 for descriptions). This profusely illustrated book will provide many answers for those who may be unfamiliar with the common minerals and rocks.

UNIT OBJECTIVES

At the end of this unit the student should be able to:

SECTION A

1. *DEMONSTRATE* how to determine the streak of a mineral.
2. *RECOGNIZE* that streak can be used to distinguish among some but not all minerals.
3. *IDENTIFY* by sample number those minerals that have no streak.
4. *DEMONSTRATE* a method of comparing the hardness of minerals by using a scratch test with the fingernail, copper, steel nail, file and glass.
5. *RECOGNIZE* that hardness can be used to distinguish among some but not all minerals.
6. *DEMONSTRATE* a procedure for determining whether or not a mineral sample exhibits cleavage.
7. *DISTINGUISH* between those minerals having cleavage and those that do not.
8. *DISTINGUISH* between minerals having a metallic and those having a non-metallic lustre.
9. *IDENTIFY* an unusual property of halite, calcite and galena.
10. *CLASSIFY* a mineral according to its lustre, colour and hardness.
11. *NAME* five minerals using a simple mineral identification key.

SECTION B

1. *IDENTIFY* eight different rock types using a simple rock identification key.
2. *DISTINGUISH* between sedimentary, igneous and metamorphic rocks.
3. *IDENTIFY* evidence concerning the origin of igneous, sedimentary and metamorphic rocks.
4. *CLASSIFY* and *IDENTIFY* rocks brought to class from student collections.
5. *RECOGNIZE* the difference between a mineral and a rock.

ACTIVITY 1

SECTION A

OBJECTIVES: At the end of this activity the student should be able to:

1. *DEMONSTRATE* how to determine the streak of a mineral.
2. *RECOGNIZE* that streak can be used to distinguish among some but not all minerals.
3. *IDENTIFY* by sample number those minerals that have no streak.

MATERIALS: (for 7 groups of 4)

28 streak plates
18 baggies numbered 1 to 18
28 copies of Student Sheet MR1

1 mineral chip set.
Use samples numbered 1 to to 14 inclusive and numbers 22, 26, 34 and 36

Remove the minerals from their plastic coating and place each in a separate plastic bag. Label the bags from 1 to 36 and insert the appropriate mineral. Do this for two of the three sets ordered.

The first property to be examined is that of streak. Streak is simply the colour of the fine powder of the mineral which can readily be seen if the mineral is rubbed on a piece of unglazed porcelain (streak plate). Note that some minerals will be too hard to leave a streak on porcelain.

Seat the students in seven groups of four. Pass out a set of three minerals and a streak plate. Demonstrate the technique required by rubbing a piece of galena (#6) across a streak plate in one stroke. Ask two or three students to describe the streak colour (lead grey).

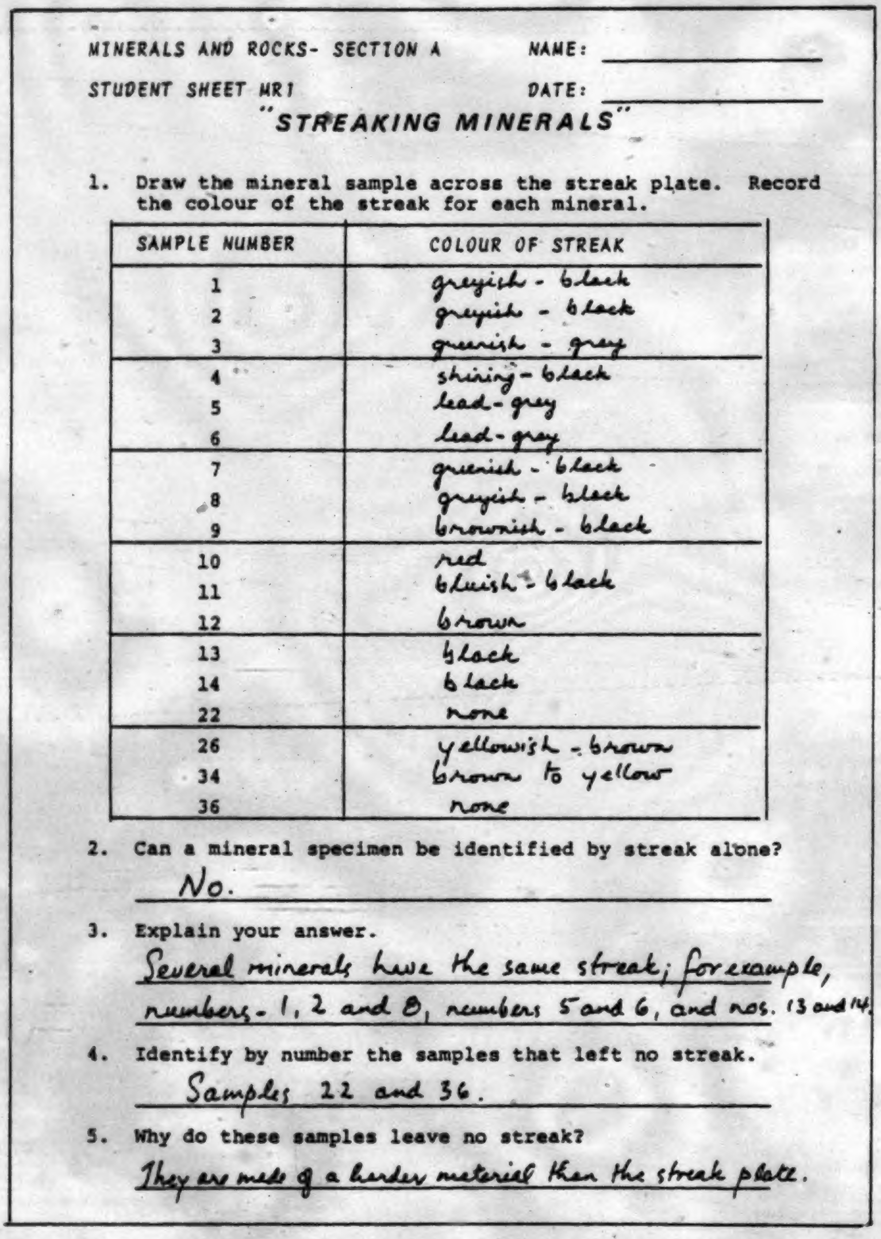
Pass out Student Sheet MR1 and have students complete the exercise.

The mineral samples should be distributed to each group as follows:

Group A - Samples 1, 2 and 3)
Group B - Samples 4, 5 and 6)
Group C - Samples 7, 8 and 9)
Group D - Samples 10, 11 and 12)
Group E - Samples 10, 11 and 12)
Group F - Samples 13, 14 and 22)
Group G - Samples 26, 34 and 36)

Refer to the Mineral Chip Manual for specimen name and streak

Have each group exchange samples with five other groups so that each student determines the streak of all eighteen samples. Once the students have completed Student Sheet MR1 review the answers for questions 2 to 5 with them. Emphasize that while streak is an important clue in mineral identification, it is only one of several that are required before a mineral can be named with certainty. The next few activities stress other clues.



MINERALS AND ROCKS- SECTION A NAME: ____________

STUDENT SHEET MR1 DATE: ____________

"STREAKING MINERALS"

1. Draw the mineral sample across the streak plate. Record the colour of the streak for each mineral.

SAMPLE NUMBER	COLOUR OF STREAK
1	greyish - black
2	greyish - black
3	greenish - grey
4	shining - black
5	lead - grey
6	lead - grey
7	greenish - black
8	greyish - black
9	brownish - black
10	red
11	bluish - black
12	brown
13	black
14	black
22	none
26	yellowish - brown
34	brown to yellow
36	none

2. Can a mineral specimen be identified by streak alone?

No.

3. Explain your answer.

Several minerals have the same streak; forexample, numbers - 1, 2 and 8, numbers 5 and 6, and nos. 13 and 14.

4. Identify by number the samples that left no streak.

Samples 22 and 36.

5. Why do these samples leave no streak?

They are made of a harder material than the streak plate.

ACTIVITY 2

SECTION A

OBJECTIVES: At the end of this activity students should be able to:

4. *DEMONSTRATE* a method of comparing the hardness of minerals by using a scratch test with the fingernail, copper, steel nail, file and glass.

5. *RECOGNIZE* that hardness can be used to distinguish among some but not all minerals.

MATERIALS:

- 28 pennies or pieces of copper
- 28 minerals, numbered and placed in baggies
- 28 copies of Student Sheet MR2
- 28 glass plates
- 28 steel nails
- 28 files

Hardness is the ability of a mineral to resist scratching. It can be measured and is another useful clue in mineral identification. A rough approximation of hardness can be made as follows:

HARDNESS SCALE	*SAMPLE NUMBER*
Can be scratched easily by a fingernail	3, 4, 5, 15, 16
Can be scratched with a copper coin	6, 11, 17, 18, 20, 24, 29, 33
Can be scratched with a steel nail	7, 8, 19, 25, 30, 34
Can be scratched with a file	1, 2, 9, 10, 12, 13, 14, 21, 26, 27, 31, 32, 35
Will scratch glass	22, 23, 28, 36

Students will need help in deciding whether a mark made by a mineral or copper or glass is a scratch. Gypsum for example may leave a white powder or streak when it is rubbed on glass, however, the powder can be easily rubbed off the glass. This shows that the mark was not a scratch and that glass is harder than gypsum. The mark made by quartz or glass cannot be rubbed off. It is a scratch. Use this example to introduce the students to the technique of determining hardness.

Advise the students that a systematic approach to determining hardness is advisable beginning with the fingernail test and working up to using the file. In this way considerable time will be saved and a minimum of scratching will appear on the surface of the mineral.

Pass out Student Sheet MR2 and have the students complete the first two questions. Review the answers and then hand out the minerals to the seven groups according to the schedule on the following page.

Have the students simply rank their set using the criteria already outlined. Allow individuals to compare rankings and resolve difficulties by further testing. If time permits allow the students to exchange sets of minerals. Place the rankings from the following page on the chalkboard so that students may check their own answers.

STUDENT GROUP	MINERAL NUMBER	MINERAL NAME	HARDNESS
A	3	Molybdenite	soft
	6	Galena	
	7	Chalcopyrite	to
	12	Chromite	
	22	Quartz	hard
B	4	Graphite	soft
	11	Manganese ore	
	8	Pyrrhotite	to
	9	Pyrite	
	23	Quartz	hard
C	5	Stibnite	soft
	17	Muscovite	
	19	Barite	to
	31	Apatite	
	36	Tourmaline	hard
D	15	Talc	soft
	18	Calcite	
	25	Siderite	to
	13	Ilmenite	
	22	Quartz	hard
E	16	Gypsum	soft
	20	Anhydrite	
	30	Fluorite	to
	14	Magnetite	
	23	Quartz	hard
F	3	Molybdenite	soft
	24	Phlogopite	
	34	Sphalerite	to
	21	Albite	
	28	Garnet	hard
G	4	Graphite	soft
	29	Asbestos	
	7	Chalcopyrite	to
	27	Microcline	
	36	Tourmaline	hard

MINERALS AND ROCKS - SECTION A
STUDENT SHEET MR2

NAME: ____________
DATE: ____________

"HARD AS NAILS"

1. Try to scratch a penny with the point of a steel nail. Then try to scratch the steel nail by rubbing a penny across it.

   a. What did you observe? The steel nail scratched the penny, but the penny would not scratch the steel nail.

   b. Which material is harder?

   The steel nail

2. Scratch one of your fingernails by rubbing the edge of a penny firmly across it. Then try to scratch the penny with your fingernail.

   a. What does this indicate about the hardness of the penny compared to your fingernail?

   The penny is harder than the fingernail.

3. A simple hardness scale is given below. Use it to place, in order of increasing hardness, the five minerals provided your group. Work on your own then compare your ranking with others in your group. Test again if you have any disagreements.

HARDNESS SCALE	SAMPLE NUMBER	
Can be scratched easily with a fingernail	3, 4, 5, 16	softer
Can be scratched by a copper coin	6, 11, 17, 18, 20, 24, 29, 33	
Can be scratched by a steel nail	7, 8, 19, 25, 30, 34	to
Can be scratched by a file	1, 2, 9, 10, 12, 13, 14, 21, 26, 27, 31, 32, 35	
Will scratch glass	22, 23, 28, 36	harder

4. Can hardness alone be used to identify a mineral? Explain your answer.

   No. Some minerals have the same hardness and could not be identified by this method alone.

ACTIVITY 3

SECTION A

OBJECTIVES: At the end of this activity the student should be able to:

6. *DEMONSTRATE* a procedure for determining whether or not a mineral sample exhibits cleavage.
7. *DISTINGUISH* between those minerals having cleavage and those that do not.
8. *DISTINGUISH* between minerals having a metallic and and those having a non-metallic lustre.
9. *IDENTIFY* an unusual property of halite, calcite and galena.

MATERIALS:

Labelled samples of GALENA, FLUORITE, MICA, CALCITE, QUARTZ and HALITE
3 or 4 hammers
3 or 4 pieces of cloth
28 hand lenses
28 copies of Student Sheet MR3 and MR4

Two other important mineral properties are lustre and cleavage. Lustre is the way a mineral surface reflects light. Some minerals have the appearance of metal-pyrite, galena, magnetite and graphite are examples. This appearance is known as metallic lustre. It is only necessary that students distinguish between metallic and non-metallic lustre. Show them the samples listed above and select from the mineral set a few others having a non-metallic lustre. A simple comparison should be all that is required.

PART A

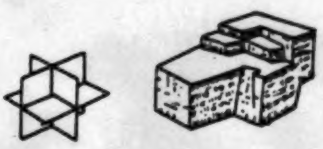
Cleavage is another property that can be used to help identify a mineral. It is the tendency of certain minerals to break along one or more planes under stress. Demonstrate this to the class by striking a piece of galena gently with a hammer. Pass the chips to each student group and have them examine the results with a magnifying lens. Have the students draw an enlarged diagram of the mineral chip and describe its appearance. They should note that the break or cleavage surfaces are at right angles to each other to give six smooth surfaces.

PART B

Provide each group with small samples of halite or calcite or fluorite. Tell them which mineral they are to examine. Ask them to place the mineral on the floor and strike it GENTLY with the hammer. If the mineral breaks along regular surfaces it exhibits cleavage; if the break is irregular it shows no cleavage. Have them draw the cleaved sample carefully paying particular attention to the number of directions in which it breaks. Sample drawings are shown below.

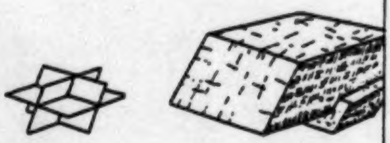
GALENA, HALITE

Cleaves in three directions. Cleavage gives six smooth faces at right angles.



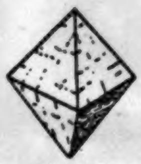
CALCITE

Cleaves in three directions. Cleavage gives six smooth faces but not at right angles.



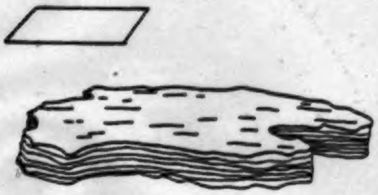
FLUORITE

Cleaves in four directions to give eight smooth faces.



MICA

Cleaves in one direction.



PART C

Next pass out a samply of quartz. Have the students wrap the quartz in a piece of cloth or several layers of paper towelling and then strike it with a hammer. Ask them to make a drawing of the chips and compare it with the previous samples for cleavage. Quartz exhibits no cleavage. Instead quartz breaks in an irregular way showing a fracture pattern quite like ripples or a pond. This "ripple" fracture is known as conchoidal fracture (conch - a shell). It is this characteristic that allowed early man to use flint to make his tools and weapons.

PART D

Finally have the students examine one of the samples of mica (biotite, phlogopite or muscovite). They should make a drawing and indicate whether or not this mineral shows cleavage and, if so, in how many directions. Often cleavage faces are confused with crystal faces. It is sometimes possible to distinguish between crystal faces and cleavage faces by the degree of roughness. Cleavage faces can be rougher. This can be tested by breaking the mineral and comparing cleavage faces. This property of cleavage can be used for trimming specimens. Students might be interested in knowing that the diamond cutter can select a flawless, perfect part from a natural crystal by cleaving it. The diamond cutter had better know the exact cleavage direction for if he places the cutting blade in any but the precise direction of cleavage the diamond will shatter into many pieces because although it is hard it is also brittle.

This activity should allow students to determine lustre and at least gain a cursory knowledge of cleavage. Only the advanced student should delve into the relationship between cleavage and atomic structure and for obvious reasons none should be encouraged to begin mineral identification by hammering a sample to determine its cleavage.

MINERALS AND ROCKS - SECTION A
STUDENT SHEET MR3

NAME: ______________________
DATE: ______________________

"BROKEN DOWN CRYSTALS"

PART A MINERAL SAMPLE- GALENA

1. Draw a large diagram of a cleaved chip of galena.
2. How many smooth or nearly smooth faces do you see on the chip? Six.
3. In how many directions did the galena break or cleave? It breaks in three directions. It is a cube.
4. Describe the lustre of this mineral. metallic.
5. What unusual property does galena have? It is very heavy for its size or volume.

PART B MINERAL SAMPLE - HALITE

6. Draw a large diagram of the cleaved halite chip.
7. How many smooth or nearly smooth faces do you see on the chip? Six.
8. In how many directions did the halite break or cleave? It breaks in three directions. It is a cube.
9. Describe the lustre of this mineral. Non-metallic.
10. What unusual property does halite have? It has a salty taste.

MINERAL SAMPLE - CALCITE

11. Draw a large diagram of a cleaved calcite crystal.
12. How many smooth faces does it have? Six.
13. In how many directions did the calcite break or cleave? It cleaves in three directions.
14. How does the shape of the broken calcite crystal compare with the shape of a piece of galena or halite? The sides of the calcite crystal are not at right angles to one another.

MINERALS AND ROCKS
STUDENT SHEET MR 4

15. If the calcite crystal is transparent you may be able to detect an unusual property. Draw a cross and place the calcite over it. Describe what you see. Two crosses are seen. It looks like this #.

16. Describe the lustre of calcite.
Non-metallic.

MINERAL SAMPLE - FLUORITE

17. Draw a large diagram of a cleaved chip of fluorite.

18. In how many directions did the fluorite break or cleave?
Four.

19. How many smooth faces does a cleaved fluorite crystal have?
Eight.

20. Describe its lustre.
Non-metallic.

MINERAL SAMPLE - QUARTZ

21. Draw a diagram of a cleaved quartz sample.

22. How did the way in which it fracture differ from all the samples you have examined so far? It did not break cleanly to produce a smooth face.

23. Suggest a use to which quartz might be put because of the way it fractures.
Since it breaks in an irregular way and leaves a sharp surface, it could be used to cut other materials.

24. Describe its lustre.
Non-metallic.

MINERAL SAMPLE - MICA

25. Break a piece of mica with your fingers. Draw this piece of mica.

26. In how many directions did it cleave? One.

27. Describe its lustre.
Non-metallic.

ACTIVITY 4

SECTION A

OBJECTIVES: At the end of this activity the student should be be able to:

10. *CLASSIFY* a mineral according to its lustre, colour and hardness.

11. *NAME* five minerals by using a simple mineral identification key.

MATERIALS: (for each group of 4 or 5 students)

4 glass plates
4 streak plates
4 copper coins
4 steel nails
1 file
1 magnet
for each student: one mineral sample found in the identification key
1 copy each of Student Sheets MR5 and MR6
5 copies of Student Sheet MR7

This activity gives students the opportunity to identify minerals based on information gathered about their streak, hardness, lustre, colour and any special or unusual property.

Instruct the students to use the key in the following way: First decide if the mineral has a metallic or non-metallic lustre. If it is metallic then work through the mineral descriptions given. Most of the minerals in this category can be identified easily because of some distinctive property listed. If the mineral is non-metallic the student should test to see whether it will scratch glass. Again distinctive properties will allow rapid identification.

For non-metallic minerals that are light coloured again separate those that do scratch glass from those that don't. Identification can then be made from the individual descriptions.

Provide each student with a copy of Student Sheets MR5 and MR6, and five copies of Student Sheet MR7. Have the students work in six or seven groups at tables provided with hand lenses, streak plates, copper coins, steel nails, files, glass plates, a magnet and one mineral sample per student. Select only those samples described on the mineral identification sheets. Students should be able to identify five mineral samples in one period. During subsequent periods the students may, at the teachers' discretion, delve further into the properties, occurrence and uses of minerals. Some time may also be devoted to the identification of minerals brought to class by the students. In this case it is wise to obtain a number of references. In order of preference they are:

MINERALS AND ROCKS - SECTION A

STUDENT SHEET MR5

NAME: ______________

DATE: ______________

MINERAL IDENTIFICATION KEY

NON-METALLIC LIGHT COLOURED

Does not scratch glass (soft)

CALCITE - white, yellow to colourless. Double image seen when clear crystal is placed on printed page. Can be cleaved. Especially common in limestone, marble and chalk.

GYPSUM - fine grained to sugary. Sometimes is fibrous form or in transparent platy crystals. Generally white. Used to make plaster of paris and as a filler in cement industry.

TALC-- usually white or light green Feels greasy. Easily marked with fingernail. Used in making ceramics, paint, rubber, insecticides, in roofing industry and for talcum powder. Soapstone is a form of talc.

MUSCOVITE MICA - occurs in flakes and platy crystals. Cleaves easily into thin sheets. Usually colourless. Used as an electrical insulator.

ASBESTOS - green to white. Fine hair-like crystals parallel to one another. Can be woven into fireproof cloth.

FLUORITE - cubic and eight-sided crystals. Glassy lustre, commonly violet, green or blue. Some minerals fluoresce brightly. Name means to flow and it does melt easily. Used as a flux in steel making, in enamelling cookware and in glass manufacture.

Scratches glass (hard)

QUARTZ - often six-sided crystals with pyramid ends. Horizontal marks on crystal faces. Most common, widely distributed mineral

TOURMALINE - crystals often shaped like prisms. Usually black, sometimes blue, pink or green. Coloured varieties are used as gemstones.

ALBITE - normally white. Two good cleavages at right angles. Glassy to pearly appearance. This is a common feldspar found in many igneous rocks.

MICROCLINE - usually pink or red. Reflects light with a glassy or pearly lustre. Especially common in granites.

MINERALS AND ROCKS - SECTION A

STUDENT SHEET MR6

NAME: ____________

DATE: ____________

MINERAL IDENTIFICATION KEY

Metallic lustre with black, greenish-black, or dark green streak

MAGNETITE - strongly magnetic, black. Important ore mineral of iron.

GRAPHITE - lead pencil black, smudges fingers. One of softest known substances Used as a lubricant and in making pencils.

PYRITE - brassy yellow colour known as "fool's gold" but is much harder than gold. The most common sulphide mineral. Used in production of sulphuric acid.

CHALCOPYRITE - brassy yellow, softer than pyrite may be tarnished purple. Most important source of copper.

GALENA - grey metallic appearance, distinct cubic cleavage. Heavy. Principal ore of lead and an important source of lead.

PYRRHOTITE - bronze coloured, werkly magnetic. Converted to iron ore and sulphur.

MOLYBDENITE - greasy feel, bluish-grey colour. More metallic and heavier then graphite. Has greenish-grey streak while graphite has a black streak.

ARSENOPYRITE - white metallic colour. Emits garlic odour if heated. Principal source of arsenic.

STIBNITE - will melt in match flame. Cleaves in one direction. Needle like crystals. Most important source of antimony.

Non-metallic, dark coloured

Does not scratch glass (soft)

BIOTITE - commonly in flakes Cleaves readily into thin sheets. Found in many rocks.

HEMATITE - reddish brown to steel grey. Red streak is distinctive. The most important source of iron.

LIMONITE - yellow to dark brown. Powdery or earthy appearance. Streak is yellow-brown. Important ore mineral or iron.

SIDERITE - crystals usually brown. Glassy or pearly shine. An ore mineral of iron.

SPHALERITE - chief ore of zinc. Pale orange to deep red and black. Streak is pale yellow-brown. Grains glitter when rotated.

Scratches glass (hard)

GARNET - usually red. Often occure as 12 sided crystals. Very hard. Used as an abrasive.

HORNBLENDE - crystals usually dark green or black. Shows cleavage. Common in igneous and metamorphic rocks.

MINERALS AND ROCKS - SECTION A NAME: __________

STUDENT SHEET MR7 DATE: __________

"THE PROSPECTOR'S TEST FOR GREEN HORNS"

See how well you can identify the five mineral samples given you. Use the two sheets that make up the *MINERAL IDENTIFICATION KEY* to assist you or any other reference given you by the teacher. Decide on the mineral's lustre and hardness. Then list three or four other properties especially any distinctive characteristics.

SAMPLE # ___

METALLIC LUSTRE	NON-METALLIC LUSTRE		NON-METALLIC LUSTRE	
	Dark Coloured		*Light Coloured*	
☐	☐		☐	
	Scratches Glass	*Does not Scratch Glass*	*Scratches Glass*	*Does not Scratch Glass*
	☐	☐	☐	☐
Other Properties	*Other Properties*		*Other Properties*	
______	______		______	
______	______		______	
______	______		______	

MINERAL NAME ☐

Optional

1. What commercial use, if any, does this mineral have?
____
2. What elements does it contain?
____
3. Does it have an unusual property? If so, what is it?
____
4. Where is it found in important quantities?
____
5. In what major type of rock is it usually found?
____

SECTION B

OBJECTIVES: At the end of this section the student should be able to:

ACTIVITY	
1	1. *IDENTIFY* eight different rock types using a simple rock identification key.
	2. *DISTINGUISH* between sedimentary, igneous and metamorphic rocks.
	3. *IDENTIFY* evidence concerning the origin of igneous, sedimentary, and metamorphic rocks.
	4. *CLASSIFY* and *IDENTIFY* rocks brought to class from student collections.
	5. *RECOGNIZE* the difference between a mineral and a rock.

MATERIALS:

ACTIVITY	*DESCRIPTION*
1	10 samples each of slate, schist, granite, limestone, pumice, sandstone, basalt, obsidian and quartzite 28 hand lenses 28 glass plates 28 copies each of Student Sheets MR8 and MR9

ACTIVITY 1

SECTION 8

OBJECTIVES: At the end of this activity the student should be able to:

1. *IDENTIFY* eight different rock types using a simple rock identification key.
2. *DISTINGUISH* between sedimentary, igneous and metamorphic.
3. *IDENTIFY* evidence concerning the origin of igneous, sedimentary and metamorphic rocks.
4. *CLASSIFY* and *IDENTIFY* rocks brought to class from student collections.
5. *RECOGNIZE* the difference between a mineral and a rock.

MATERIALS:

10 samples each of slate, schist, granite, limestone, pumice, sandstone, basalt, obsidian and quartzite
28 hand lenses
28 glass plates
28 copies each of Student Sheets MR8 and MR9

Arrange the students in five groups and give each group two pieces of granite, sandstone fossil and limestone. Explain to them that to identify a rock you do not have to test it as you do a mineral. There are only a few different kinds of rock and most can be identified by sight.

Ask the students to identify any similarities or differences between these rock samples and the mineral samples studied in the first four activities. List any observations made. They should be able to point out that the varied colours and textures of these samples indicate that they are composed of several minerals rather than one. Stress this difference so that students understand the distinction between a mineral and a rock.

Ask the class to identify the rocks that may have formed under water. Have them support their suggestions with observations. They may indicate that the fossil limestone and the the sandstone have been deposited in water. Tell them that these are sedimentary rocks. Provide students with hand lenses so that they can examine the particles in the rocks.

MINERALS AND ROCKS - SECTION B NAME: ____________________

STUDENT SHEET MR8 DATE: ____________________

"FOR ROCK HOUNDS"

To identify a rock you should first determine its texture or the size of the minerals or other rock fragments that compose the rock. The texture is coarse or medium if you can see the minerals without a hand lens. It is fine if you can see the minerals only by using a hand lens. If no minerals can be seen, even with a hand lens, the texture is very fine.

Aside from the texture of the rock you should also determine what minerals it contains. This should not be too difficult except for rocks with a fine or fine grained texture. For these rocks you may have to depend on the hardness or colour of the rock.

Lastly you should examine the rock to see if it splits along definite planes of weakness. Sedimentary rocks such as shale, sandstone and some limestones as well as some metamorphoric rocks such as slate usually split along planes of weakness quite easily.

ROCK IDENTIFICATION KEY

If you can see minerals in the rock sample try to identify them first. Then find the answer to the question on line A. Your "yes" or "no" answer will guide you to the next question to be answered. This should enable you to identify the rock if it is one of 14 listed here.

A. Can you see individual minerals or particles of rock without using a hand lens? If yes, see line 1 below; if not, see line B.

1. Are the minerals distributed at random? Are the minerals tightly locked together, making the rock hard to split? If yes, see line a, below. If no, see line 2.

   a. Are the minerals mostly light-coloured, largely quartz, feldspar and mica. If yes, see line 1 below. If no, see line b.

      1. If the mineral particles are less than ¼" in size, but all are about the same size the rock is Granite.

      2. If the mineral is interlocking calcite, which will not scratch glass, the rock is Marble.

2. Are the minerals arranged in planes or bands which tend to split along these planes? If yes see lines a and b, below; if not see line 3.

Next have students examine the piece of granite. Explain that it is an igneous rock having a somewhat different mineral composition and certainly a different origin than the sedimentary rock. Ask the students to identify the minerals in the rock. They can compare them with biotite mica, feldspars and quartz in the mineral collection. Tell them that geologists give granites different names according to the presence of certain minerals but that these three minerals are found in nearly all granites.

From this introduction students may proceed to rock identification using a simple key. Once they have named the rock they may then use references to determine further information including the rock's origin and characteristics.

The rock types to be examined are SLATE, SCHIST, GRANITE, LIMESTONE, PUMICE, SANDSTONE, BASALT, OBSIDIAN and QUARTZITE.

Answers to questions 11, 12, and 13 can best be found in one of the references listed on page 21. *ROCKS AND MINERALS* by Joel Arem is the best for this purpose.

MINERALS AND ROCKS

STUDENT SHEET MR8 (Cont'd)

a. If the plates of the lined - up minerals are quite thin the rock is a schist.

b. If the aligned minerals show as broad bands of alternate light and dark minerals, such as quartz and felspar in the light layers and mica and hornblende in the dark layers, the rock is a gneiss.

3. Is the specimen made up of rounded mineral particles or other rocks? If yes, see lines a and b below.

a. If the particles are large, rounded pebbles the rock is a conglomerate.

b. If the particles are sand-sized grains, mostly of quartz, the rock is a sandstone.

B. If the particles of mineral or rock can barely be seen, even with a hand lens see line 1 below. If not, see line 2.

1. If the minerals are tightly locked together, making the rock hard to split see lines a, b and c. If not, see line 2.

a. If the minerals are dark coloured, such as hornblende and feldspar, and the rock is dark grey or black and will scratch glass, it is basalt.

b. If the above description applies but the rock has many tiny holes, it is Scoria.

c. If the mineral is largely light coloured quartz that is fused together, and will scratch glass, it is quartzite.

2. If the individual particles of rock cannot be seen with a hand lens, but the rock appears to be layered, and is too soft to scratch glass see line a, below. If not, see line c.

a. Does the rock split easily into layers. If yes, see lines 1 and 2 below. If not see line b.

1. If the lustre on the split surface is dull, the rock is shale.

2. If the lustre on the split surface is silky the rock is slate.

b. If the rock is made up mostly of calcite and does not split into layers it is probably limestone.

MINERALS AND ROCKS

STUDENT SHEET MR8 (Cont'd)

C. If you cannot see any minerals, even with a hand lens, see lines 1 and 2 below.

1. If the rock is light - coloured and contains many holes (that sometimes allows the rock to float), it is pumice.

2. If the rock is jet black with a glassy lustre and a shell like fracture, it is obsidian.

Conglomerate, sandstone, shale and limestone are SEDIMENTARY ROCKS.

Granite, basalt, scoria, pumice and obsidian are IGNEOUS ROCKS.

Marble, schist, gneiss, quartzite and slate are METAMORPHIC ROCKS.

MINERALS AND ROCKS - SECTION B NAME: ____________

STUDENT SHEET MR9 DATE: ____________

"ROCK DESCRIPTIONS"

Examine the following **IGNEOUS** rocks and answer these questions.

GRANITE 1. How would you describe the texture of this rock?

Coarse grained with interlocking grains.

2. What three minerals are prominent in this specimen?

Quartz, mica, and feldspar.

3. What gives this piece of granite its distinctive red colour?

The feldspar present in the rock.

4. Where might such a rock be found in Alberta?

In the portion of Alberta on the Canadian Shield, that is, in the far northeast corner of the province. Granite boulders can also be found in gravel pits.

5. What commercial use does this rock have?

As a building stone.

PUMICE 6. What is the most unusual feature of this rock?

It is full of gas holes and is very light.

7. Place the sample in a container of water. Does it float?

Yes.

8. The holes in this rock were caused by gas bubbles. How might this rock have formed?

By volcanic action. The gas bubbles up through the molten rock during volcanic action.

OBSIDIAN 9. This glassy rock has the same chemical composition as pumice but appears quite different. The way it formed accounts for this. Explain.

Obsidian is a natural glass. It cools so quickly during volcanic action that crystals do not have a chance to form.

MINERALS AND ROCKS - SECTION B

STUDENT SHEET MR9 (Cont'd)

10. Ancient man used this rock to make tools and weapons. What property of the rock allowed this to be done?

Its property of breaking like glass into curved surfaces with very sharp edges.

BASALT 11. Basalt is the most common of the five grained igneous rocks and makes up large volumes of materials found in lava flows. Describe how this rock is formed.

SANDSTONE AND LIMESTONE 12. Describe these specimens noting especially how they differ. If any loose grains are present examine them with a hand lens. What is the mineral composition of these grains? Find out how these sedimentary rocks were formed.

SCHIST AND SLATE 13. Describe these metamorphic rocks. Pay special attention to any unusual features of these rocks. Find out how they were formed.

OPTIONAL: Bring any of your own rocks or minerals to school. Use the key to identify the specimens and the references available in your school to find out more about your samples.

APPENDIX E

Classroom Arrangements for Science Class
In Eddington and Northland Schools

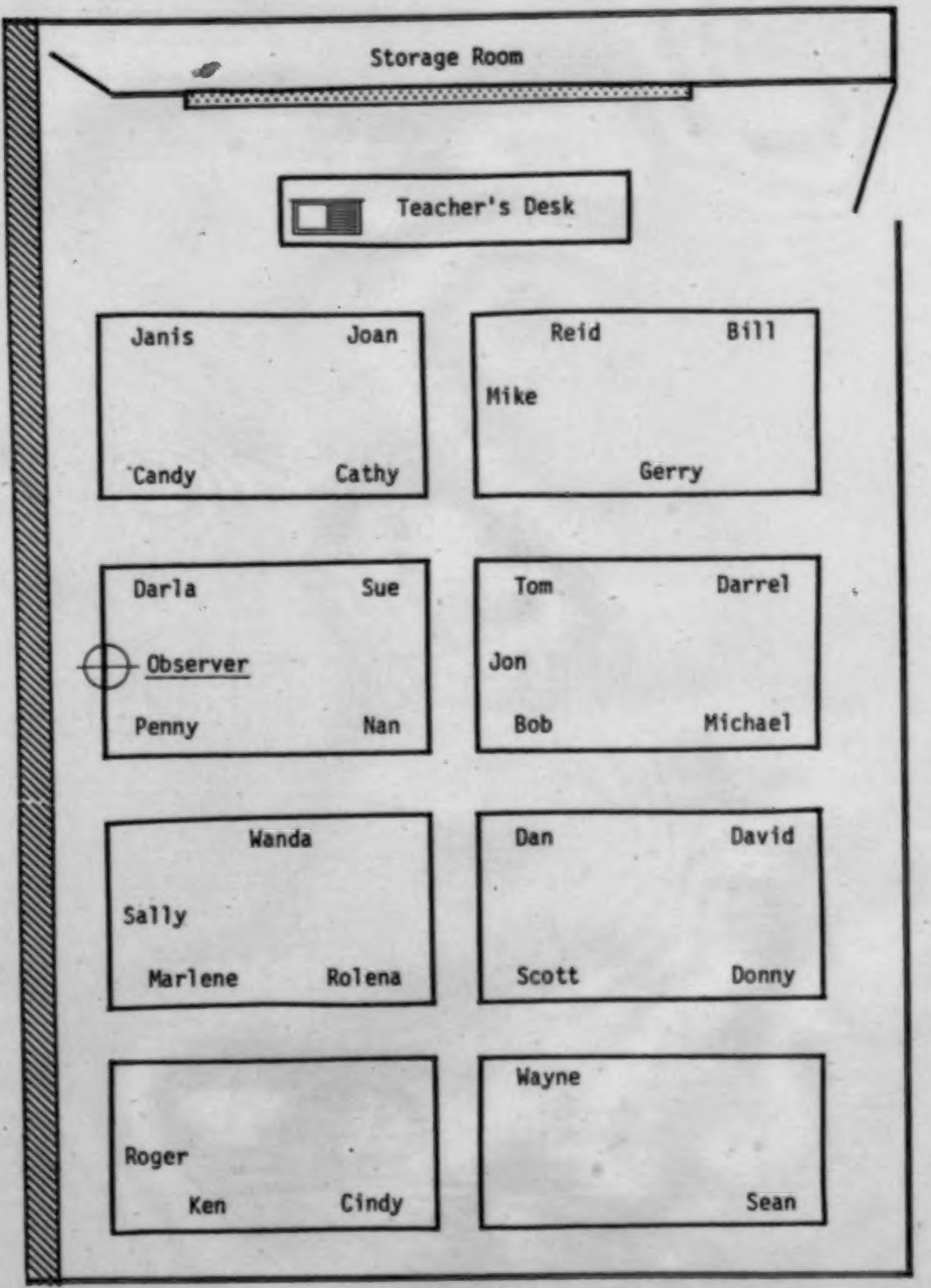

Storage Room
Teacher's Desk
Janis
Joan
Candy
Cathy
Reid
Bill
Mike
Gerry
Darla
Sue
Observer
Penny
Nan
Tom
Darrel
Jon
Bob
Michael
Wanda
Sally
Marlene
Rolena
Dan
David
Scott
Donny
Roger
Ken
Cindy
Wayne
Sean

Figure A. Classroom arrangement for grade six science class at Eddington School.

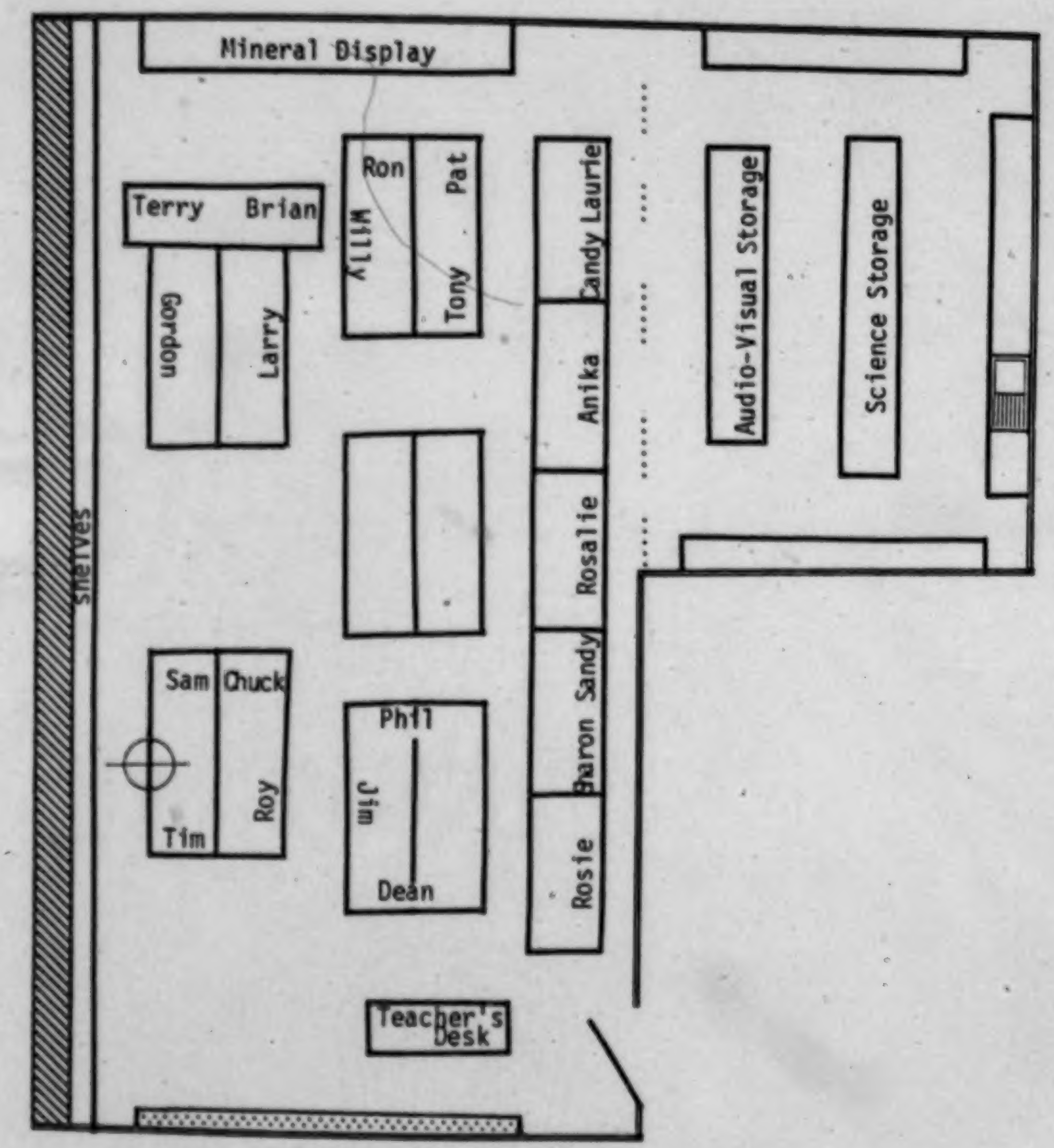

Mineral Display
Terry
Brian
Gordon
Larry
Ron
Pat
Willy
Tony
Candy
Laurie
Anika
Rosalie
Sharon
Sandy
Rosie
Audio-Visual Storage
Science Storage
Shelves
Sam
Chuck
Tim
Roy
Phil
Jim
Dean
Teacher's Desk

Figure B. Classroon arrangement for grade six science class at Northland School.

APPENDIX F

Selected Transcripts of Class Activities At Northland and Eddington Schools

Northland School-Hardness

Day I: [Class enters room after lunch break, collects materials from home tables and moves into science groups. Teacher begins explaining the science unit about to be studied]

Teacher: You'll be pretty much on your own - reading the directions and things and figuring out what to do. I'll be handy if you get stuck, but for the most part I'd like you to handle this matrial as much as possible on your own. This may mean there is quite a bit of discussion going on so remember how loud you get.

This is a bit of background information. According to one of the books there are over 2000 different kind of rocks and minerals. And one of the things we're going to have to ask ourselves is, what is the difference between a rock and a mineral? Just in making up the booklets someone mentioned that a rock is a fairly large piece of stone or whatever and would perhaps be made up of mainly one kind of mineral or perhaps many kinds of minerals. So all of the examples at the back of the room might be considered rocks made up mostly of one kind of mineral. As you might expect many of these minerals are rare. Can you name some that might be rare?

John: Gold.

Teacher: Gold is a good example.

Sam: Diamond.

Teacher: O.K. That's interesting that you named those two if they are indeed minerals, because what comes to mind when you think of gold and diamond?

Gary: Expensive.

Teacher: O.K. The fact that they're rare and the fact that they're expensive. O.K.. Then there's another interesting statement about these. 2000 are common or fairly common. In fact, it said, common enough to be called rock. So, maybe this business that we talked about at the beginning is not right. 40 minerals are common enough to be called rock--that's an interesting statement. Now one final thing. Ten of these minerals make up most of the earth's crust-most of the hugh chunks of rock that are underneath the soil. The purpose of this unit is to decide what belongs where, as far as rocks and minerals are concerned, and to give us some means of identifying some. We could perhaps name some when we're finished and you should be able to do some tests on different rocks--perhaps from these tests you will be able to tell me what they are. For instance, if I pulled a couple of rocks out of my pocket you might be able to do several tests on it and say, "This is probably this kind of mineral."

Anytime you do this of course, you are looking at something we call properties. So I suppose minerals might have different kinds of properties just like plants have different kinds of properties. What might be one property -- one characteristic?

Sarah: Hey--some of those big ones are heavy and small rocks come out of big rocks when they're broken down.

Teacher: Anything else?

Tim: Colour.

Teacher: Anything else that comes to mind?

Sam: Hardness - like some you can't break. Like you have to use so much "acid" or something. (Class begins the streaking activity. After completing streaking activity, the class begins working on the hardness activity.)

Teacher: We're going to look at the first two questions on the next unit. If we're working with streaking in Investigation One, what does it look like we're testing in Investigation Two?

John: The fingernail and the penny.

Teacher: We're testing the fingernail and the penny. Can you be more general?

Jim: We're going to check the hardness of rocks.

Teacher: He says were going to test hardness. Terry?

Terry: The hardness.

Teacher: You agree - just at what you're glanced at. (Teacher passes put pennies and nails) To do these activities you do need a penny and a fingernail and a nail. (Students begin working on Q 1 and Q 2.)

Sam: (Scratches penny with nail) Look how shiny it gets - takes off the paint (tarnish).

Chuck: It takes off the paint.

Tim: O.K. what did you observe?

Sam: It takes the paint off.

Tim: That isn't paint.

Sam: That is so.

Roy: It took the paint off for (a)?

Sam: How about "it takes the tarnish off?" (All write it down.)

Roy: It took the tarnish off (copies from the rest).

Tim: Reads (b): "Which material is harder?"

Sam: The nail.

Chuck: The penny. Nail!! I can't bend a penny. I can bend a nail. [Hardness associated with bending]

Tim: You can't bend it (nail). If you could stretch a penny I bet you could bend it.

Chuck: O.K. Try to bend the nail.

Roy: Look, he's trying as hard as he can. (Tim tries to bend nail-nothing happens.)

Chuck: Hey, look.

Tim: Look, Chuck! (Tim hits penny with nail.) See, you can see a hole by the maple leaf. (Can't bend nail so tried to hit penny with the nail.) [Breaking criterion]

Chuck: (Examining nail Tim tried to bend) Oh, it did.

Sam: Let's see that hole. (All try to dent the penny. They pound both penny and nail.)

Teacher: O.K., we're waiting for people to answer 1 and 2.

Tim: O.K. What does it say? (Reads Q2) "Scratch one of your fingernail by rubbing the edge of a penny firmly across it. Then try to scratch the penny with your fingernail."
What? (Doesn't understand what to do - reads it again).

Roy: The metal is a lot harder than the fingernail.

Tim: I got a hammer once and battered a bunch of pennies.

Sam: That's a disgrace to the queen.

Tim: Yah, I know.

Teacher: Are these coated nails? Would that make a difference if they were coated nails?

Chuck: Yah.

Sam: Probably not-----

Tim: You don't know anything, Chuck.

Chuck: (Pounds penny with nail using streak plate as a hammer; other pounding is going on in the classroom. Discussion follows about hitting fingernails which then turn black and blue and come off.)

Teacher: O.K. what did you find out? Chuck, Q1?

Chuck: Took the tarnish off it.

Teacher: What is it?

Chuck: The penny took the tanish off.

Teacher: The penny took the tarnish off-----

Sam: The nail took the tarnish off!

Chuck: The nail took the tarnish off.

Teacher: That's what you should write down. When you come back in a week or month from now you won't know what you meant. Tom?

Tom:	The outer coating of the penny came off.
Teacher:	O.K. Tim?
Tim:	Like you know when they make the pennies they're all shiny and then during the years they get that gloss that's stuck on them.
Teacher:	The nail takes that off?
Tim:	Yah, but what causes it to get that black stuff on?
Teacher:	That's caused by oxidation - would that help?
Tim:	Somehow the air makes something on the penny come out?
Teacher:	You're close.
Bob:	Copper.
Teacher:	Roy, what did you decide for (b)?
Roy:	The steel nail.
Teacher:	How many agree? (all agree) In the second question you were supposed to scratch your fingernail by rubbing the penny firmly across it. Then try to scratch the penny with your fingernail. Q2 (a) "What does this indicate about the hardness of the penny compared to your fingernail?" Willy?
Willy:	I don't have that question.
Teacher:	What would you say now?
Willy:	----------
Teacher:	You don't know? Sandie? What would you say?
Sandie:	Your fingernail is softer.
Teacher:	How many agree? (3/4 agree). So, some say differently?
John:	They're about the same.

Chuck: No way!! (penny harder than finger nail)

Teacher: How many say the same? (3). If we were to write these from soft to hard which would we put as the softest?

Pat: Nail.

Teacher: You'd say the nail is the softest? What's the hardest if the nail is the softest?

Pat: The fingernail is the softest (changes his mind - not sure though).

Teacher: What's the hardest, Laurie? [Establising order of hardness for penny, nail and fingernail]

Laurie: The nail.

Gloria: It's too hard to tell.

Teacher: What do you say comes in between? Tom?

Tommy: The penny. (all agree)

Teacher: Let's keep that in mind. We'll use it later.

Tim: It's hard to tell which is hardest because if you take all the tarnish off and see what scratches right through to the penny, then it isn't easy to tell and also the nail has a point on it and the penny doesn't ---so that could be---- [Recognizing variables affecting scratch identification]

Teacher: So you wouldn't necessarily put it in that order. Would you want to change it?

Tim: I'm just not sure.

Pat: I think the penny is harder, but the nail bends. The penny is probably the hardest. [Bending associated with hardness]

Teacher: We may have some problems with this.

Pat: Well, a nail bends but a penny doesn't.

Tim: Like you can get a hammer and you can-like I did it before and I ruined a penny. I bashed it all up but with a nail it's harder. [Associating hardness with malleability (experience)]

Teacher: O.K. So you'd agree with that list?

Sam: I think I know another way to figure it out. Put it in an oven and crank it up all the way and see which one melts first. [Associating hardness with ease of melting]

Teacher: So, basically what you're saying--the harder something is--what--

Sam: Well, I think it would be the nail cause steel is used in pots and pans and it never metls. They don't use copper that much. They use cast iron in roasters and stuff. That's not the same as steel is it?

Teacher: No, it isn't.

Jerry: You could make a nail shaped like a penny and see if the nail would bend first. [Associating hardness with bending]

Teacher: If you made a nail shaped like a penny and hammered the nail and the penny too, do you think you could tell which was harder?

Gloria: The nail would bend first. [Hardness vs bending not resolved]

Jean: The penny (Discussion ensues - no agreement; students don't agree that you could make such a comparison.)

Teacher: O.k. Let's review. What was the reason for the first investigation? Tim?

Tim: To find out what colours of streak the rocks make.

Teacher: O.k. and Investigation 2?

Terry: If the nail is harder than the penny.

Teacher: O.k. I think what we'll do is try some more minerals and do some more work with this part.

April 29, 1977

Northland School-Hardness

Day II: [Interviewer arrived 10 minutes early; set up recorder at usual table. Teacher came in and outlined the up coming activities: redo Q1 & 2; complete MR2; note difficulties from previous day - evidence of scratching, what makes something hard, and so forth.]

Teacher: We need to discuss the copper penny. Remember you were talking about the fact that the copper penny was coated with something? And when you scratched it the tarnish - was it acutally the copper or the tarnish that was scratched? Then we discovered we had nails that were coated and when we rubbed it with the penny the coating came off and we couldn't really tell whether or not the nail itself was scratched. You'll have to look very carefully to see whether or not the nail itself was scratched. You'll have to look very carefully to see whether the material itself is scratched, or whether the material you're scratching with just leaves a mark on it. It's something like the blackboard and the chalk. If I draw a line across there (does so) it left a mark on it, but it certainly didn't scratch it. (Teacher illustrates "rubbing off" techqniue) It can be rubbed off. You have to scratch that. Anything else we need to know?

You'll be marking some things on glass and that's really when this business will come into play. If you make a mark using this glass, you rub it with your hand to see if it actually scratched the glass or whether it just left a mark. I think we'll repeat the first part or MR2 just to check things out. (explaining experimental procedures) I got some different nails and I'll give you another batch of pennies and we'll take a close look at it. Then we'll go on to Q3 which gets a little complicated.

In Q1 you have to try to try and scratch a penny with the point of a steel nail. In Q2 you have to scratch the fingernail by scratching the edge of the penny across it. Then you try and scratch the penny with your fingernail and by doing this sort of thing we get different levels of hardness. If you look at Q3, you'll see they put a hardness scale there. It goes from the fingernail to the copper coin to the steel nail to the file to the glass. Now unfortunately, we only have four files because our order is backordered (shortage of equipment). So, we'll have to share. You can use one file between two groups.

Now there may be a problem with determining how hard a rock is. Where do you start? (Pause) Does it matter? (Pause) Take #7 for example. What would you do? Would you see if it scratched glass first or would you see if you could scratch it with your fingernail or does it matter what order you go in. [Order of testing makes a difference] I'm looking at the hardness scale in Q3. (Sam is listening to the teacher; other students are reading MR2) Willy?

Willy: Order doesn't matter.

Teacher: It doesn't matter what order you go in. O.k. Think about it for a moment--------. Should you have some kind of a system?

Willy: Maybe ------

Teacher: [Suggests ideal, systematic approach for testing the minerals - begin with softest test instrument and work toward hardest.] I think it would be wise, because if you don't start at one end and go through to the other, you'll forget which one you tested. That's one possibility. Secondly, the time involved. If you go from one to the other, you'll have to give them all five tests where as if you start with one and work through. As soon as one test works you don't have to go any further. So, let's start there at the top. Try the fingernail, then the copper coin, then the steel nail, then the file and then the glass.

I'll pass out one penny and one nail to each group again. Retest it while I'm passing the other materials but. (Teacher passes out matrials; students begin to retest.)

Sam: Rub it off to see if it scratchs the tarnish off or if it scratched it.

Tim: It scratches the penny (nail on penny-testing for whole group).

Sam: Did it?

Tim: Yah, you can't rub it off.

Sam: There, it does scratch it. It's a new penny too, so it doesn't have any tarnish on it. If it were a new penny it wouldn't have tarnish on it.

Chuck: Is that a new penny?

Sam: It's a 1977 - says so right there. The steel nail scratches (nail on penny) so we've right on both counts.

Chuck: (Chuck doen't have a nail so he uses a quarter; thinks a quarter is usually of steel? Scratches penny on quarter and copper powder is left behind.) I got an old quarter there, see how much it does scratch (copper coin scratches quarter).

Sam: (Tries for himself on the copper coin.) There it does scratch the penny.

Interviewer: Which is harder, the copper coin or steel nail?

Sam: The steel nail.

Chuck: The penny.

Sam: The steel nail.

Chuck: I say penny.

Interviewer: Why do you say penny Chuck?

Chuck: Well, take a look at this (penny on quarter).

Sam: That's copper, not steel!

Chuck: Oh-----.

Interviewer: Yes, but can you tell from the scratching? Can you tell from this (penny and nail) which is harder?

Tim: Look, how about copper where, for instance, that can easily be bent. [Bending criterion]

Interviewer: Yes, but what about what happened here (penny and nail)? Can you tell anything from that?

Tim: [Ignoring question of scratching, focusing instead on bending] See, bend that nail [continuing with bending idea from previous lesson].

Chuck: See if you can bend the copper penny-----. That nail is harder. (Problem of bending=hardness. Tim concerned with bending, also Chuck; Sam uses evidence from the investigation as basis for his reasoning.)

Interviewer: What can you tell from what happened here?

Sam: The steel nail is harder.

Interviewer: How do you know?

Sam: Cause you can see there is copper on this (nail). That means that this (penny) is softer.

Interviewer: So that means the nail is harder than the penny?

Sam: Yah.

Interviewer: Is there another way of saying that?

Sam: -----------------

Interviewer: Could you say anything about the penny compared to the nail?

Sam: -----------------

Interviewer: What about the chalk on the board? Which is softer?

Chuck: Chalk.

Sam: Chalk.

Interviewer: How do you know?

Chuck: You can grind it (chalk) up.

Sam: It might not be softer -- it's just that it's chopped up - cause they're cliffs made up of chalk. [Hardness associated with grinding and chopping.]

Tim: It's easily grinded. (Teacher passes out mineral samples.)

Tim: How may rocks in the bag?

Roy: Got only four (takes sample #4; Roy listens to discussion; doesn't add to it or get involved.)

Chuck: Five. (Teacher begins discussion of investigation; conversation cut off.)

Teacher: Each of you should have five small bags and a large bag.
(Student's remove minerals from bags.)

Chuck: This is a mineral?

Teacher: Terry, what does Q3 say?

Terry: (Reads Q3) "A simple hardness scale is given below. Use it to place in order of increasing hardness, the five minerals provided your group. Work on your own then compare you ranking with others in your group. Test it again if you have any disagreements."

Teacher: O.K. Do we work together or separately?

Terry: Together.

Sarah : Together.

Sam: We work separately and then compare with your group members. (General confusion over directions.)

Teacher: So, each one works by themselves and then compare with the others to see what they got. If you don't agree then you'll have to try again. Now, we may have time to do two bags.

Sam: Looks like red marble (36). Smells like peanuts.

Teacher: What are we trying to do?

Sam: Test the hardness.

Teacher: How are we going to go about that?

Students : Um-----.

Teacher: Our old problem back again. Have a look at that scale to get an idea.

Sam: By testing with a fingernail.

Teacher: O.K. Supposing you take #6. Rosie has #6. Can you scratch it with your fingernail?

Rosie: (Does so) No.

Teacher: Where do you put it? So would you put #6 under "Samle Number" (on worksheet)?

Sam: What do you mean by sample number? (Students talking; seem to be confused.)

Teacher: Just listen. Let me talk to Rosie. If you can scratch #6 with your fingernail, you would put it beside "Can be scratched easily with fingernail." You would put #6 there. But, since you can't, what will you do? Take the copper coin. "Can be scratched by a copper coin". Can you scratch it with a coin? (Meanwhile students are examining their specimens; a few are listening.)

Sam: (To himself) This (36) is really soft. (Uses fingernail to scratch it; then penny.) Naturally if you can scratch it with your fingernail------.

Teacher: [Teacher aware that students are having trouble with hardness scale; they don't know how to use it.] O.K., each of you take a sample. Doesn't make a difference which it is and start. Can you scratch it with your fingernail?

Students: I can. No. Yes. No, etc.

Teacher: Just listen. If you can, you write the number beside "Can be scratched with finger nail". If you can't, you go on to "Can be scratched with a penny."

Sam: It's (36) crumbling. (Pieces of 36 break off with scratching and a little chipping.)

Sam: (Testing 36-Tourmaline)

Roy: (Testing 27-Microcline)

Chuck: (Testing 7-Chalcopyrite)

Tim: (Testing 29-Asbestos)

Chuck: I need the nail (for 7; starts with nail, not fingernail).

Roy: (27) Doesn't scratch.

Sam: I think this (36) has got tar on it. (Notices tournaline crystals.)

Chuck: "Can be scratched by a file." We don't have a file. (Fingernail and penny don't scratch it.)

Sam: I need a penny (proceeding in order).

Tim: The penny scratches this (29).

Roy: The penny scratches it (27). O.K. "Can be scratched by a file (Tries all tests, proceeding in order but records in all blanks; doesn't stop when he finds a test that "works.")

Chuck: I scratched it (7) with a nail. I put several scratches in it. I scratched it with a nail and a file.
(Students appear to have difficulty understanding how to use the Hardness Scale. Sam is o.k. - follows in order and stops after he finds a test that works. Chuck, Tim and Roy use all of the tests and write in all the blanks. See worksheets.)

Chuck: Need a penny?

Roy: No, I need a nail.

Tim: Look! Neat! Watch. I got a rock (29), that sheds. Teacher, look! (Teacher joins group) I got a rock (asbestos) that you can take some things off of it (very excited).

Teacher: Can you scratch it?

Tim: Yah, the nail scratches it (not proceeding in any order).

Teacher: You try and scratch it with your fingernail. If you can, you put the number there. If you can't, you try the penny. If not, you move up to the next one and keep going.

Tim: You mean-----.

Chuck: Teacher, do we get one glass each? You mean the rock will scratch it?

Sam: I got the glass, too, and I don't think the file is going to work (on 36). Hey. it's (glass plate) like a magnifying glass. (He looks at mineral through the glass plate, noticing some magnification.)

Chuck: Have you finished with the file? (takes file)

Interviewer: Chuck, does it make a mark? (File on 7.)

Chuck: (Files 7.) Yah. (Students file the minerals rather than scratching them.)

Interviewer: Does it rub off?

Chuck: Mine don't rub off.
(Teacher walks around stopping to talk with students answering questions.)

Roy: Mine does (Filing on 27).

Tim: Oh yah!! (Filing 29).

Sam: The file doesn't even file the stuff (36).

Tim: Sam----
(Teacher stops to talk with interviewer. Remarks that students are recording in all the blanks)

Sam: Yah, it (36) scratched (the glass) and you can't take it (the mark) off either. (Sam works alone; follows hardness scale, unaware of the others. [Most students recording in all blanks. Use of table confusing?]

Chuck: Hey, I'm filing the rock (7). Look!

Interviewer: What happened Tim?

Tim: It makes a hole in the rock (filing 29-asbestos). So, the file can scratch it. (referring to minerals in rocks)

Teacher: (Noticing the children are recording a particular sample number in more than one blank; attempts to clarify use of table). (To class) It seems to me you can't have a number any more than one place. Now, I may be wrong but if we're trying to see how hard the rock is, we're trying to see if it's somewhere between soft, fairly soft and quite hard and we have to find the place to put it. Now let's suppose that we take #12. Suppose I try to scratch it with my fingernail and it doesn't scratch. Would I put it by "Can be scratched easily with a fingernail?" So, I then take 12 and try and scratch it with the copper coin. Supposing it will not scratch, will I put the number beside that space?

Jamie: No.

Teacher: O.K. Then I try and scratch it with a nail. It won't scratch with a nail so I don't put it there. Then I try and scratch it with a file. It scratches with the file. What should I do?

Gloria: Write the number.

Teacher: Right. I write the number next to "Can be scratched with a file." O.k., if it can be scratched with a file do you think it's hard enough to scratch glass?

Roy: No.

Teacher: No, probably not. So it is not worth going any further than that. Now, does this solve anything or not? I say several people had the same number all the way up. They said they could scratch it with their fingernail and then the said it would scratch glass. That doesn't seem logical. if you can scratch the rock with your fingernail, is it in fact scratching the glass or can you rub it off and find out whether it scratched the glass?

John: Have to see whether it scratched the glass.

Teacher: If it is an actual scratch, then you shouldn't be able to scratch it with your fingernail. O.K., carry on. (While teacher talks, students play with glass. Teacher attempts logical discussion. Only a few students sit quietly and listen; most continue to "work". Students continue to test each mineral with all objects on scale; they still don't appear to understand how to use the scale.)

Tim: We have to compare (the results).

Interviewer: Can you comapre (your results) if the others haven't tried all the minerals?

Chuck: (File on 7 - last test). Tim, what did you get? (Tim is interested in following directions of the questions; wants to compare results after he has done one sample.)

Tim: What did you get, Sam?

Sam: Well you don't compare. Everybody has to do the rocks.

Interviewer: (Clarifying teacher's directions) Can you compare your's with Sam yet, Tim? (Sam hasn't done 7 yet.)

Tim: No-----.

Interviewer: So what do you have to do next?

Tim: Change rocks.

Sam: This (29) is a fairly soft rock (fingernail on 29).

Chuck: Oh, neat man! (Filing on 7.)

Sam: You're right Tim. This (29) chips; it sheds. This thing is probably the stuff they use in cloth.

Interviewer: What number is that Chuck (filing on 7)?

Chuck: #7.

Sam: (Noticing the white fibres, but doesn't know what part of the specimen to test. He begins with the fingernail) Teacher, I need some help on this. Look, it's (29) a two-parted rock. If you do that (scratch fiber part) it scratches. But if you take the rock, it don't (black part doesn't scratch). I'll see if the nail scratches it. Yah, it does so I don't know where to put it, because, look you can scratch it with your fingernail.

Chuck: Does a steel penny scratch this (36) now? (Copper coin on 36.)

Sam: No, it doesn't scratch the nail - the penny or whatever it is.

Chuck: I made a mark and I can't rub it off.

Sam: It took me to the glass. You can rub this off (the glass). There is a little scratch so I'll put it under first.

Roy: (Copper coin on 4; fingernail on 4; file on 4; nail on 4; records after fingernail, after copper coin.)

Chuck: You done with 29?

Interviewer: What did you decide to do with 29, Sam?

Teacher: (Helping Roy.) The number should only go down once, Roy. (27 recorded after copper coin nail and glass)

Roy: It (27) scratches glass.

Teacher: You mean it (27) actually scratches the glass and you can't rub it off?

Roy: Nope. (Tries again on glass and rubs off.)

Teacher: That means it's pretty hard.

Tim: Chuck, you finished yet with 7?

Roy: This doesn't scratch the glass (7 on glass; not following order).

Chuck: You're supposed to start at the top (of hardness scale).
(Roy has 27 written in three places. After discussion with teacher he rubs out all but glass; Roy appears to use no systematic plan-at least not as teacher had instructed; Sam does; Tim continues to record in all spaces as does Chuck.)

Sam: (Testing 27; Starts at top and works down to file.)

Chuck: You can start with the nail, Sam?

Sam: No, you start with the fingernail.

Tim: Here's 36. (has tested fingernail on 36, 36 on glass, nail on 36, copper coin 36, file on 36; records after glass and nail)

Chuck: What number is this - 29? Do I put 29 here (next to copper coin)?

Roy: No, you need the nail.

Sam: Now, let's see. (files 27)

Interviewer: What would you say about the hardness of that Sam?

Sam: It's pretty hard.

Interviewer: Why?

Sam: It takes a file to saw it (27).

Interviewer: Does the file make a mark on it?

Sam: Yah. (records after file)

Roy: I need 29. (fingernail on 29, records after fingernail)

Sam: (Takes 7) I bet this is copper. (compares 7 with pyrite)

Interviewer: Why?

Sam: It don't know. I just think it's copper. (uses copper coin, then nail)

Chuck: (Erases 7 from two spaces and then has one entry in each space; doesn't use hardness scale in order. Using 4 he begins with the copper coin, glass, nail and file; doesn't record anything.)

Sam: Steel nail doesn't (scratch 7).

Chuck: I need 26.

Sam: There is no 26.

Tim: Holy cow! (4)

Roy: Does it scratch?

Sam: Try your fingernail first.

Tim: Wow, 4 (Graphite) is a weak one. (Fingernail on 4; copper coin on 4; records after fingernail and copper coin on hardness scale)

Sam: Take a look at the table. It's all black (Testing 4).

Tim: Try the steel nail now.

Sam: You can only have one number on the line. (Notices that Tony wrote a sample number in all spaces.)

Tim: Why? I don't get this (trouble recording; gets annoyed)

Sam: We do like this (writes number down) and then we compare our answers.

Tim: What do you mean?

Sam: We'll do every rock and when you're finished everybody compares answers. You say "Well, I go -----you say what you got for each hardness and if they're wrong you have to do the tests over again.

Tim: Well, I'm doing it my way!!

Sam: You have to do it the way the teacher said.

Tim: (Proceeds to copy some answers from Sam's results; copper coin on 4; fingernail on 4; file on 4.)

Teacher: (Joins group; comes to discuss with Sam and Tim.)

Sam: He (Tim) said we should compare our answers, but he thinks that comparing answers means doing one and then copying everybody else's answer.

Sam: Tim has 4.

Teacher: (To Tim) O.K. 4 will only go in one place. How hard is it? O.K. once you've determined how hard it is, that's where you put it. (Tim doesn't erase anything; Teacher then helps Roy; gives group bag D)

Chuck: (Takes 25; starts with penny; records 25 after copper coin hardness scale.)
(15-Talc; 18-Calcite; 13-Ilmenite; 22-Quartz; 25-Siderite)

Roy: (Takes 22; fingernail on 22; nail on 22; doesn't follow order of hardness scale).

Sam: (Takes 13; fingernail on 13) Can't scratch it with your fingernail. Hey, this is coal. (copper coin on 13).

Roy: You can scratch this one (22). (Nail on 22.)

Interviewer: What does it do, Roy? What does it tell you?

Roy: ---------- Doesn't scratch the nail. (22 on nail.)

Sam: You can do it (scratch it) with a copper coin (13). That's sulfur or some kind of sulfate. (Records after copper coin.) I got 18 (Calcite) now.

Chuck: What is this (22)?

Roy: Oh, it scratches all right. (Nail on 22; records after nail.)

Sam: Hey, it's crystal. I bet it's (18) quartz.

Interviewer: What do you mean by crystal?

Sam: Like the quartz - like the crystal or whatever - on the board back there (back of classroom). They have quartz. I think this is quartz. I should go back there and compare it. What do you say?

Roy: Look at all the marks (on mineral).

Sam: And it (18) doesn't cut the penny (18 on copper coin). Give me the nail.

Interviewer: What number do you have Tim?

Tim: 13. (13 on glass.)

Interviewer: What have you found out about it? Anything?

Chuck: Crystal quartz (22). (22 on copper coin; nail on 22; records after nail; doesn't rub off.)

Tim: I don't know (Tests 13; gives it away.)

Sam: The nail does it on 18.

Roy: I need 15.

Sam: Let's see if I can get a piece of this (18) off. (Tries to chip piece off with finger nail.)

Chuck: Anybody need 13? (Cooper coin on 13; fingernail on 13; file on 13; 13 on glass; records after glass.)

Roy: It (15) crumbles.

Sam: I'm trying to break it (18) (Bangs 18 with file).

Tim: I don't get how you do this. (Takes 25 and begins with glass again.)

Sam: I'm trying to break a piece off.

Tim: Do you put down the one that could be scratched with your fingernail the easiest? [Doesn't understand the chart] This is a dumb chart!

Roy: Man -- it (15) just crumbles. (Roy continues to break the talc; seems fascinated with it (fingernail on 15, nail on 15; records after fingernail and nail.)

Chuck: This (18) feels funny. (18 on copper coin; file on 18; records after file; Roy watches Chuck and records 18 after file, copying Chuck's answers.)

Sam: (To Chuck) You don't do it with all of them - just until you find one that will break it.

Discussion

Teacher: Set down the rocks. You obviously ran into problems. What kind of problems?

Students: -------------(no response; students continue working)

Teacher: No problems at all?.........O.K. now don't change any answers on your sheet. According to the tests by people who know what they're doing, this is the level of hardness. The softest rocks -those that can be scratched with your fingernail are: 3,4,5,16. You didn't do

all those rocks but how many got some agreement? (Students raise hands) (8 agreed).
(1) Fingernail: #3,4,5,16 (8 agreed)
(2) Copper coin: 6,11,17,18,20,24,29,33 (6 agreed)
(3) Nail: 7,8,19,25,30,34 (9 agreed)
(4) File: 1,2,9,10,12,13,14,21,26,27,31,32,35 (8 agreed)
(5) Glass: 22,23,28,36 (14 agreed)
The next set could scratch with a copper coin. See if you have any agreement here: 6,11,7,18,20,24,29,33.

Student: Do you have to have all of them?

Teacher: No. You only did some of them.

Teacher: Next category, "Can be scratched by a steel nail": 7,8,19,25,30, 34. How many got some agreement? (9 agree).

Teacher: Next, "Can be scratched by a file": 1,2,9,10,13,12,21,26,27, 31,32,35. How many agreed with at least one? (8 agreed)

Teacher: According to the hardest one: 22,23,28,36. How many got one of these? (14 agreed)

Teacher: You should have agreed that the steel nail scratched the penny, but the penny would not scratch the steel nail. Q1. (a). For Q1. (b), "From that you should decide that the steel nail is harder." Q2: You should have decided the penny is harder than the fingernail So, you have a ranking of hardness - fingernail, penny, steel nail- that was given to you in the scale below. Having worked with some of those rocks, you can now take a look at Q4 below, if you haven't already done so. "Can hardness alone be used to identify a mineral?" Explain your answer. So, you have to say yes or no and say why.

Roy: No.

Teacher: Not right now.
(Group not sure of Q4; no agreement; haven't had time to answer it because they have been testing hardnesses).

Interviewer: Why is it tough (to answer Q4)?

Sam: You think it is because it's difficult to tell what is harder..... then you think you know....

Interviewer: Tim you said you think you know.
(Roy appears to be thinking; looks around; so does Chuck; Sam doesn't know; Tim says "no" as does Roy, but Roy (doesn't-can't?) think of reason.)

Tim: --------

Roy: I say no.

Teacher: But, you have to write down how come.

Roy: I know (can't give a reason; looks around; Roy and Chuck look at Sam's answer. Tim decides on his own. Sam says "yes".)

Teacher: We'll have to stop at this point. Jim, what were you going to say? What conclusion did you come to?

Jim: Because many rocks have the same hardness.

Teacher: So if that's the case, you'd say "no".

Sam: I say "yes" because different minerals have different hardnessess.

Teacher: But the thing is, can you tell what the mineral is?

Sam: Sure, if you had the right chart about how hard they are.

Teacher: So, what we need to do is find out if such a chart exists.

Sam: Yah.

Teacher: Where?

Sam: At these scientist who work on all these minerals.

Teacher: That's a possibility.

Sam: Geologists.

Teacher: You could check with a geologist. He would be able to tell you or at least be able to tell you where to look. OK. if you can't find a geologist, where else would you look?

Sam:	Encyclopedia or in that magazine geologists use.
Student's:	What't the answer?
Teacher:	The answer in the book? No, we have to work with confusion for awhile (because of study). (Student's anxious for "right" answers; science class ends; students pack up their belongings - begin to return to their "home desks". Sam and Chuck help to pack up tape recorder for me. I say goodby to group and teacher who is already organizing for next class and leave).

May 2, 1977

Eddington School-Hardness

Day I: (Lab) Teacher begins class discussion by introducing the idea of rock characteristics. Student's are asked to name some characteristics.

Teacher: This was a scientific word for smoothness or roughness. What do we mean exactly by -- shape?

Reid: They weigh more.

Teacher: You know you can find big rocks and small rocks of the same shape. There is a special scientific word for weight. This is density. We'll talk about that later. What about shape? Is that any indicator?

Lily: ..... rounded flat.

Teacher: Some would be flat and some would be rounded with different places.

Joan: Some rock might shine.

Teacher: In other words some rocks might be a shiny texture or shiny lustre. O.k. there is also a special word for this.

Susan: ------(inaudible).

Gerry: Where they were formed.

Teacher: That's an excellent indicator. You wouldn't find diamonds in your back yard.

Jon: Well, you can if you look hard enough.

Teacher: Can you, Jon?

Jon: All you have to have is a piece of coal that will turn into anthricite, then diamond.

Teacher: How long does that take?

Jon: Two million years. And it also will need a lot of pressure.

Teacher: What was another thing you were going to tell us, Jon?

Jon: My uncle whenever he goes to work he brings a rock back and he goes to the mountains and they have a beach with hugh different coloured rocks.

Teacher: O.K. so that's where - location.

Jon: Maybe that's because the water smoothed out the rocks. The roughness of the mountains depends on water and ----.

Teacher: That's interesting, Jon, because the water wears the mountains down by erosion.

Student: (Inaudible)

Teacher: Not really, it is a little different than that.

Jon: Like when it's water it keeps the moisture in the rocks. In the mountains you have a piece of wood and a little water and it becomes harder and harder. And if you had a piece of wood by the ocean it has moisture and gets softer.

Teacher: When it's petrified it gets hard doesn't it?

Jon: Yah!

Teacher: How is petrified wood formed?

Jon: You have water and years and years it's pushed together and takes the moisture out of it - the pressure. But if it was a piece of wood by the water it would get moisture by the water.

Teacher: How many of you have seen petrified wood before? Where you seen it? (Most have seen it- 3/4 of class.)

Joe: By the sea rocks.

Teacher: And it wasn't really a rock was it?

Janis: Not a rock.

Teacher: Then it's not really a rock then. How did that happen?

Susan: ------

Teacher: How did you know it was petrified wood?

Susan: Well------.

Tom: I saw some on my neighbors lawn.

Teacher: Your neighbors lawn. How did it get there?

Tom: I don't know.

Teacher: Was it a sort of decoration?

Tom: Yah.

Teacher: [Teacher suggests hardness as a topic for study. Mentions breaking idea] O.K. There is another characteristic of rock and minerals that you haven't mentioned that I'd like you to investigate today and this is the hardness of the rock. Now perhaps you haven't thought about this but some rocks are soft and easy to break and others are not quite as soft, they're hard. Can anybody suggest a way (to test hardness)? Supposing we had two rocks. Can anybody suggest a way we could tell which of these two rocks is harder than the other?

Jim: Break them.

Sally: Bang them on the table [Children pick up and expand breaking idea]

Teacher: You'd hit them on the floor or hit them together?

Don: On the table.

Cathy: Drop them off the table.

Teacher: What if they both broke?

Cathy: Then they'd both be soft.

Reid: The texture and the weight.

Teacher: You think that would give you an indication of the hardness? Perhaps.

Reid: Scrape it with a nail (has been looking at worksheet). [Scratching criterion suggested]

Teacher: I think somebody has been cribbing here a little bit. O.K., Reid looked it up in the material and noticed a nail used somewhere in there. Perhaps you could scratch with a nail and that could give you some indication of hardness. What you could do is try to scratch them with a variety of different things. I'll pass out this worksheet that will give you the procedure. Read it through and I'll get the materials to you. (Materials are passed out.)

Teacher: Read Question One, Reid.

Reid: "Try to scratch a penny with the point of a steel nail. Then try to scratch the steel nail by rubbing a penny across it"
(a) What did you observe?
(b) Which is harder?"

Teacher: Read Question Two, Wanda.

Wanda: "Scratch one of your fingernails by rubbing the edge of a penny firmly across it. Then try to scratch the penny with your fingernail. (a) What does this indicate about the hardness of the penny compared to your fingernail?"

Teacher: Read Question Three, Dan.

Dan: "A simple hardness scale is given below. Use it to place, in order of increasing hardness, the five minerals provided your group. Work on your own then compare your ranking with others in your group.. Test again if you have any disagreement."

Teacher: [Teacher explains hardness scale] What they've got here is five levels of hardness. Now, if you have a look at the scale there, the first level of hardness- "Can be scratched easily by a fingernail." So, just try to scratch the rock easily with your fingernail and see if you leave a mark. Now, by leaving a mark you mean a proper scratch in it. You have to be very careful with this. You'll have to make sure that it is a scratch and not just a mark. Did you actually scratch the rock or is a piece of your fingernail left sticking in there? (Doesn't demonstrate how to "rub off".)

I would suggest that you try each of the rocks by yourself. The rocks are in little plastic bags and they have numbers on them. When you have used the rocks make sure you have placed it back in the same bag. When you have tested your little sample, test the others. Test them by all the methods here. Did it scratch your fingernail? Did it scratch the

copper coin? Can be scratched by steel nail? Can be scratched by file? And finally, can be scratched by glass. Now, if you find a rock that will scratch glass, don't go scratching up the glass and make a big mess of it. Just make a small scratch and use it as a scientific investigation. Some of the rocks may scratch glass while many may not.
(Group work: students read lab sheet and begin to work.)

Penny: (Reads 1(b) and scratches penny with fingernail.)

Nan: (Watching Penny work) You're supposed to do it against a rock, dummy!

Sue: You scratch it with your fingernail!

Darla: You scratch it (mineral) with the nail - it leaves a scratch mark on the rock. (Doesn't rub off.)

Sue: When I scratch this rock (with fingernail), guess what happends? Particles come out. [Rock=mineral]

Nan: (To Sue) So, that's the nail grinding up silly! That doesn't make it scratch. I want a penny. [Mineral harder than fingernail?]

Sue: Darla, is this (the particles) part of my nail?

Darla: Yes.

Penny: Some dirt comes off (the penny).

Sue: (Reading) Try and scratch a penny with a steel nail
No, You did!

Sue: Yah, I saw it happened.

Darla: (Reading) 'What did you obsrve?'

Sue: You get a scratch on the penny.

Penny: The dirt comes off the penny. Read: 1 (b) "Which material is harder?"

Darla: (After writing "The dirt comes off the penny." - Penny's answer) "Which material is harder?"

Penny: The penny is harder.

Darla: Then why does it (nail) scratch it (penny)?

Penny: (Reading) Which material is harder? I think the penny is harder.

Darla: [Reasoning logically] But Penny, why does this (nail) scatch that (penny) instead of this (penny) scratching that (nail)?

Penny: [Not associating hardness with scratching; hardness associated with bendability] Which is harder, not which one scratches! You could bend this (nail) it would be pretty hard to bend a penny.

Darla: Yah. But if the penny were round and skinny you could! (But records Penny's answer anyway, i.e. "The penny is harder".)

Penny: (Reads Q2) "Scratch one of your fingernails by rubbing the edge of a penny firmly across it. Then try to scratch the penny with your fingernail" (starts writing on glass with a pen).

Sue: Number 22 (quartz) is pretty. Look!

Darla: Ooooohhhh , Yucky, it's really yucky.

Nan: I've seen candy that looks like that.

Darla: Penny, don't write on the glass.

Nan: Don't fool around on the microphone. You're just wasting tape.
Get to work. (Darla had picked up the microphone.)

Darla: The teacher's (Interviewer) wasting tape! O.K. (Reads Q2; students discuss note written by Sue. Students select minerals by how nice they look.)

Penny: (Reads Q 2(a)) "What does this indicate about the hardness of the penny compared to your fingernail?" (Scratches penny with fingernail and fingernail with penny.)

Interviewer: (To Nan) Does the mineral (12) scratch the nail? (The harndess of the penny and my nail is about the same; the penny made a slight mark on the nail - erases the first past and leaves "the penny made a slight mark on my nail".)

Nan: No.

Interviewer: So, is it (mineral) harder or softer than the nail?

Nan: Harder.

Interviewer: What are you going to try next?

Nan: The file. (files 12)

Interviewer: Does it scratch? (Students filing, not scratching; Penny tries her mineral on the glass).

Nan: This (mineral). (12 scratched.)

Interviewer: So where is that going to go? (On Hardness Scale).

Nan: (Indicates position after file; students filing away!)

Darla: Sue, you're not supposed to scratch it to death!

Penny: Nan, how do you do the chart (hardness scale). (Reading hardness scale; Nan doesn't respond. Penny watches the others-doesn't seen very interested.)

Darla: Why don't we work together? O.K. Q 3.

Student: Yah (let's work together).

Darla: (Organizing group) Put all the rocks in the bag. Who volunteers to scratch it with your fingernail? Hand in all your rocks and one person will do everything. It's the easiest.

Nan: I want to scratch the glass. (Students begin different tests.)

Teacher: I don't think we'll have time to finish today. When you finish with your samples put them in the bag.
(Student don't get organized very well. Fooling around mostly; seem easily diverted).

T6/8

Darla: We're never going to finish! Sue, do your part of the work! We'll never get done!

Nan: How many bags did we have?

Penny: What's your favourite song?
(Students don't follow much of an order in procedure; they accomplish very little on the first day; don't finish.)

April 22, 1977

Day I: Boys

Gerry: Ah, we didn't get gold!

Reid: O.K. Try to scratch the penny with the point of a steel nail (does scratch). Ah, I scratched it real easy!

Bill: "Then try to scratch the steel nail by rubbing a penny across it." (Does so.) They work.

Gerry: Can't see (the scratch).
Can you scratch the nail?

Teacher: Give it a real hard scratch across the penny.

Reid: Hey, I did. Maybe I just took the dust off. No, I didn't.

Teacher: What happened with the nail?

Mike: It got scratched.

Teacher: What got scratched?

Mike: The penny.

Reid: O.K. What did you observe?

Mike: The penny got scratched in both cases. (Records response.)

Bill: O.K. you guys, they'll know we're copying.

Gerry: The penny got scratched in each, both - cases.

Bill: (Reading) "Which material is harder?"

Mike: The nail. (Records it.)

Reid: (Examining his fingernails.) Hey, my fingernail's gone! Q2"Scratch one of your fingernails by rubbing a penny firmly across it."... (each does his own).

Gerry: (Reading Hardness Scale) How do you do this?

Bill: None of them (penny or fingernail) get scratched.

Reid: (Reading) "Then try to scratch the penny with your fingernail!"

Bill: The penny is harder.

Mike: The penny is harder. (Recording.)

Bill: What does this indicate about the hardness of the penny? It's (penny) harder. (The group moves on to the next question.)

Reid: (Reads Q3) "A simple hardness scale is given below. use it to place in order of increasing hardness the five minerals provided your group........."

Gerry: I don't get this. What is softer to harder?

Interviewer: (Intrepreting directions) That means the softest one is here and the hardest one is here at the bottom. You put the softest one here and then the next hardest on here and so on. You put them in order from softest to hardest.

Mike: Oh, that's not hard.

Reid: O.K. what do we do? (Reading) "Can be easily scratched with a fingernail." Yup.

Mike: Your's can? Let's see.

Reid: "See, right across there.

Bill: I can't tell with mine.

Mike: What's your sample number?

Bill: 27. O.K., I get this. ['Catching on' to scale?]

Reid: You have to put them in order. Hey, Gerry, what about this?
"Can be scratched by a copper coin?"

Bill: I don't understand.

Reid: "Can be scratched by a steel nail." Hey, maybe this one (new mineral?) can.

Bill: Hey, this can be scratched by a copper coin (coin on 27).

Mike: Hold it, Reid. Which end did you use?

Gerry: Hey, this (27) can scratch glass.

Reid: Does your's scratch glass? Mine (7) can scratch glass, Look at that!
See, right there.

Bill: I don't know if this a scratch or not. (Rubs off) Yah, it can scratch.

Reid: Yah, that's a scratch.

Bill: Cause when I wiped it off, it was still scratched.

Gerry: All of these can scratch glass.

Bill: I don't get what to do now.

Mike: Mine can be scratched by the nail.

Reid: Mine can scratch glass.

Gerry: Mine (29) gets scratched by everything but my fingernail.

Bill: O.K., then Gerry's will be the first. No, the second one. We need one more. We need the softest one.

Mike: O.K. give me the order.

Gerry: Did we do it right? See, we all got this. What do we do next?

Reid: I got a hole in my bag. (Students make holes in the plastic bags.) That's how hard my rock is.

Bill: (To Interviewer) Did we do ours right?

Interviewer: Did you compare and agree?

Students: Yes.

Bill: But we only have four (minerals). We need five.

Interviewer: So, you haven't got the softest one there. Why don't you do the next question.

Reid: (Reads Q4) "Can hardness alone be used to identify a mineral?"

Bill: No.

Mike: But why?

Reid: Yah, it can, but not all the time it can't.

Mike: I wonder if we can hear this back again. I don't sound good on the tape recorder. Tape recorder. Can you hear me?

Teacher: (Asks for attention) The noice level is getting too high here. It doesn't look like we'll get this finished today. What I suggest you do is finish with the mineral sample you're working with and when you have finished, tidy up put them inside the bags.
(Students begin to clear up)

Bill: O.K. Mike, we have to do Q4.

Reid: Yah, well, what's the reason?

Mike: Man, you always make me do the answers.

Interviewer: How come you said, "no"?

Reid: We're still figuring it out.

Bill: There may be two rocks that - like were exactly the same hardness.

Mike: They might be invisible - you still can't see it.

Interviewer: So, you think there may be more rocks than sample 27 that will scratch it?

Gerry: Think a diamond will?

Bill: Yah.

April 22, 1977

Eddington School-Hardness

Day II: (Teacher conducts review of yesterdays activities on hardness. Task for today is to complete the hardness activity.)

Teacher: What are we doing in this experiment?

Student: Finding out what rock is softer or harder.

Teacher: How do we do that?

Student: Scratch it.

Teacher: What sort of things do you use?

Student: Penny, file, fingernail.

Teacher: The order - what is the order?

Student: Fingernail, penny, nail, file, glass. (Students are told to begin working in their groups and to complete the hardness activity. Those groups that finished a bag or minerals last day are to do a second set today). (Boys: Bag C: 7,27,4,29. Girls: Bag B: 7,3,6,22,12.)

Interviewer: What numbers did you have last time?

Nan: 7,3,6,12,22.

Students: (Continue filing the minerals; have trouble understanding the hardness scale.)

Penny: How do you do the chart, Darla?

Interviewer: That tells you the order of hardness - from softest to hardness. (Reading right side of scale) This is the softest (top) and this is the hardest (bottom)

Darla: I thought you put if it scratched glass [Note: Darla is answering the question "Will the fingernail scratch it?", "Will the penny scratch it?" for each test. She writes the number after each object that will scratch it and ends up by recording the same number in all spaces. She does'nt seem to understand how to use the scale as it was intended, rather she only answers the question "Does it scratch or not?" for each object. She doesn't go one step further to decide on the order of hardness]

Interviewer: Yes, but if it scratches glass, it means it's quite hard.

Darla: It can be scratched by a file (too). (Starts to write in file blank too).

Interviewer: Well, just put it in the last place where the hardest (unclear). If it scratches glass, will it scratch my fingernail? ...... Look at 3. If it scratches glass, will it also scratch my fingernail.

Darla: Yah (3 on fingernail).

Interviewer: If it scratches my fingernail is it harder or softer than my fingernail?

Darla: Yah, it's harder -- the rock.

Interviewer: So, would it go over there (after fingernail). Does it scratch the copper coin?

Darla: Yah, it scratches the copper coin (3 on copper coin)
(Darla continues to write the number in all the blanks as do Sue and Penny.)

Darla: See, you can put a whole bunch of numbers in here. It can be scratched with a copper coin right? (Persisting in answering questions on chart, doing so correctly.)

Nan: It can't be 3,3,3 - they're not all the same (3's in all blanks).

Penny: It goes softest to hardest - it's not all the same? (Works on her own; tests and records; uses all blanks.)

Darla: You can scratch it with this (copper coin). Right, so put 22 (after copper coin).

Nan: You know the crystal goes with the steel nail.

Darla: You put 22 with "it will scratch glass" and you have to test it to see if it will scratch glass. (Returning to her own work) "Can be scratched by a file" (7). O.K., can you scratch this file? O.K. "Can it be scratched with the fingernail?" I scratch it with my fingernail.

See, when you scratch this (mineral with fingernail) it leaves some of your fingernail.

Interviewer: (To Sue) It (file) doesn't do it very well does it. What does that mean?

Sue: ----------

Interviewer: If the file doesn't make a scratch on it, is the mineral harder or softer?

Sue: Well, it'll scratch glass.

Interviewer: Is it harder or softer than glass?

Sue: Softer.

Sue: Softer than what?

Sue: Than the glass.

Interviewer: Softer than glass or is it harder than glass?

Sue: It's, um, harder than the file but it doesn't scratch glass.

Interviewer: Does that mean it's harder or softer than glass - if it doesn't leave a scratch on there?

Sue: -------

Interviewer: This mineral leaves a scratch on here (file) and not on here (glass). What does that tell you?

Sue: It's (glass) harder.

Interviewer: The glass is harder?

Darla: O.K. we all tested the 7.
(Student's continue to have trouble deciding where to write the numbers. They continue to have problems with the deciding what is harder (the mineral or the object) when they see a scratch. They finish up testing other minerals. (Tape not clear here. After 15 minutes most groups have finished.)

Teacher: (Reviews lesson. Decides to discuss the mineral sets and the students order them from softest to hardest.) Who had Set A? What did you have for the softest one?

Group 1: 11,4,11,11,4,9.

Group 2: (didn't finish)

Group 3: 7,9,11,4-

Group 4: 22,11,9 --

Teacher: O.K. another group?

Group 5: 15,18,25,13,22 (correct order).

Teacher: Does everyone agree? (Some don't.)

Group 6: (Bag C) 17,19,31,36,5.

Student: The file will scratch 5?

Group 7: (Bag F) 24,21,3,34,28.

Girls: 22,6,12,7,3.

Boys: (Group) 6,29,4,7,27.
(Discussion goes on in groups again).

Teacher: Go on to question 4. "Can hardness alone be used to identify a mineral?

Jon: Yes. If it can scratch glass, then it's harder.

Mike: No, because there might be many rocks that can scratch glass.

Penny: Yes.

Darla: Yes.

Nan: No.

Sue: No. (Class ends for the day)

Day II Boys

(Students get minerals)

Reid: What are we supposed to do now?

Bill: Do we do the test all over again?

Teacher: No, just record if for fun.
(Student's switch bags when they finish they're own.)

Mike: This is gold.

Interviewer: How would you know gold if you saw it?

Reid: It sparkles.

Interviewer: This doesn't sparkle so it's not gold?

Reid: Well,no-----.

Gerry: It's fool's gold.

Interviewer: What is fool's gold?

Reid: That just plain old rock.

Interviewer: Where does that name come from?

Bill: It fools a lot of people.

Reid: It's not real gold.

Interviewer: Do you think this could be real?

Students: No.

Interviewer: What would happend if it were?

Bill: It's not.

Interviewer: It would be nice to think it was. Gold is expensive these days.

Students: Mica - it's mica.
(Boys do not stay on task; do some fooling around)

Students: Are you guys done?

Bill: Anybody want to trade rocks with me?

Mike: I got 27 and 28.

Bill: You don't have to know your number.

Reid: Yes, you do - to know which package it came from.

[Note: Boys do hardness tests with minerals but don't discuss them. They talk about other things (girls, and non-related talk) as they work with no mention of the minerals]

Reid:	O.K. I got this one. (Reid and Bill work quietly; seem to be task oriented).
Reid:	The teacher is a real nice guy except he has a bad back and he's grumpy today.
Teacher:	I think every guy has finished this first bag. What you have tried to do is figure the hardness, the order of hardness. On the worksheet it shows the softest to the hardest. Read first the softest one; then the next hardest and so on. [Assuming students have ordered the minerals, but most students haven't.] Set A (see worksheets); Set D: 15,18,25,13,3; Set G: 4,29,7,27.
Students:	No, 29,4 and the rest. Set F: 24,21,3,34,28
Teacher:	O.K. If I give you a rock and a table that has all the hardnessess on it, do you think you will be able to identify those minerals by their hardness?
Student:	Yes.
Teacher:	Why?
Student:	(inaudible)
Reid:	No.
Teacher:	Why?
Reid:	Because these might be more than one rock that can scratch glass.
Teacher:	Do you think you can identify a mineral just by its hardness?
Students:	No, no-----.
Teacher:	Write your answers on Q 4 and explain your answers.
Bill:	This is shale?
Mike:	What's shale?
Reid:	I don't know.

(Students go back to working; then they start blowing up the bags.)

Teacher: You have your answers for Q4?

Students: Yes.
(Boys go back to talking about the bags and other small talk. Teacher tells groups to clean up. Boys begin to work quickly in order to finish; they don't discuss what they are writing.)

April 25, 1977

APPENDIX G

List of Mineral Specimens, Recording Sheet And Questioning Guide Used in Conjunction With Post-Unit Activities

Minerals Used In The Hardness Activity

# 7	Talc
# 40	Halite
# 43	Fluorite
# 4	Apatite
# 28	Corundum

Name ______________________________

Date ______________________________

HARDNESS

Your task is to arrange, in order of increasing hardness, the five minerals provided. You might want to use the following objects to help you decide the hardness of each mineral:

file
streak plate
hammer
piece of steel
magnet
magnifying glass
copper coin
hardness scale

Observations

Use the space below to record any observations, to make notes, or to draw diagrams, etc. that will help you solve the problem.

Conclusions

When you have decided on the appropriate order, write the number of each mineral, in order of hardness, in the boxes below:

☐ ☐ ☐ ☐ ☐

softest ----------------------------> hardest

Hardness

1. What does hardness of a mineral mean to you?

   Does it mean anything else?

2. Can you show me which objects (equipment) you used to help you decide on the hardness of each mineral?

   How does a __________ help you to decide the hardness of a mineral?
   (Repeat the above question for all objects used.)

   How does the hardness scale help you to decide on the hardness of a mineral?

   Can you tell me how the scale works?

   How could you prove to me that the __________ is harder than the __________?

3. There are several objects (equipment) here that you didn't use.

   Can you tell me why you decided not to use the __________.

   Could the __________ have helped you to determine the hardness of the mineral?

   How?

4. Will you tell me how you decided on this (point to boxes at bottom of the page)?

5. Supposing you were out in the mountains and picked up these five minerals. You wanted to identify them, but you didn't have any of this equipment with you. Is there some way you could still determine the hardness of the minerals and put them in order?
   Show me how you would do it.

APPENDIX H

Selected Transcripts of Post-Unit Interviews
— Sam, Chuck, Tim, Roy, Nan, Darla, Penny, Bill, Gerry, Mike and Reid

Symbols and Abbreviations Used in Conjunction with the Interview Transcripts

7 - Talc

40 - Halite

43 - Fluorite

4 - Apatite

28 - Corundum

(2)X - number of times an operation occurred

[comment] - observer comment

(clarification) - observed behaviour or clarification

---- - short break or pause within or following an utterance

-------- - long break or pause within or following an utterance

Fingernail on 43 - implement (fingernail) used to 'test' mineral (43) for hardness

Note: Included in this appendix are transcripts of post-unit interviews with the seven primary subjects (parental permission to videotape the eighth subject was denied), the four secondary subjects and six additional subjects. For the sake of brevity only the transcripts of the primary and secondary subjects are included here, however, the results of all 17 interviews are presented in Figures 6-22.

It should also be noted that the questioning strategies presented in the transcripts do not represent a 'model' approach, being represented, rather, as they evolved during the course of the investigation.

HARDNESS

Sam: Mineral Order: 43,4,28,7,40

Interviewer: Now, in front of you are five minerals. I'd like you to put them in order from softest to hardest. You might want to use the file, streak plate, hammer, steel, magnet, copper coin, magnifier, and the hardess scale. Do you remember the hardess scale? If you want, you can write down notes on this paper and when you finish you can write the number of the minerals from softest to hardest in the boxes below.

[Minerals: 7-Talc, 40-Halite, 43-Fluorite, 4-Apatite, 28-Corundum.]

Sam: (Feels each mineral in turn -43,4,28,7 (stops and bends 7) and 40. Picks up 7 again; scrapes 7 with fingernail and writes: puts 7 aside.

Interviewer: Can you tell me what you are doing while you are doing it?.

Sam: O.K. (picks up 7) Test this with my fingernail and you can scratch it so 7 is the softest and hum-- guess I'll take 43 (fingernail on 43). Can't scratch it. Take copper coin (copper coin on 43; 7 x and rubs; 5x rubs). Well, I guess it looks like it scratched it (43 on copper coin and rubs). It can't scratch the penny so --- (43 on steel (2x); rubs). It scratches the steel. (Picks up file; file on 43(4x). Steel file scratches it, so (looks back at paper and hardness scale) - not the penny, not the fingernail, not the penny, not the steel, all-- this one --43 here (writes 43 above box four). So--- 4 (fingernail on 4) -doesn't get scratched by the fingernail (copper coin on 4 (4x)). Doesn't scratch it (4 on copper coin) and it (4) scratches the copper penny. (4 on steel). It scratches the steel plate and (file on 4) and steel file scratches it -- so this is-- put 4 here (above box five) -- could be both of them. Now 28 (fingernail on 28). That doesn't do it. (Copper coin on 28) Scratches it. And 28 on copper coin scratches it - hum- maybe I can rub it off (rubs it). Tough one here (copper coin on 28). Strange. One way I'll find out (28 on copper coin) -so-- I think it's harder, but maybe in another way it isn't. So, I'll try it (28 on steel; rubs off). (File on

4) - It scratches it. So, it's close to the penny -so-- (writes 28 above box 2). So 40. (Fingernail on 40). I don't know. So the fingernail doesn't scratch it. (Copper coin on 4) The penny does and (40 on copper coin - blows) so this doesn't scratch the penny - so that means that (crosses out 28) 40 goes here (writes in box 2) and this (28) goes down here (on top of box 3). So 40 is second softest. I know that.
Now, these devils (28,4,43).
(Copper coin on 28) So, 28 can't be that (copper coin), but it can be this (28 on steel). It's cut (then steel on 28 (6x)). It scratched it. (steel on 28 and writes). So 28 is the third softest.
43 and 4 are trouble. (Thinks - taps 28 and 4 togehter while thinking; copper coin on 4) That would not work (looks at paper). It's gotta be (thinks again) oh-- (takes piece of glass; 4 on glass). Doesn't scratch it. (43 on glass and glass on 43). So, they both don't (scratch glass). Tough decision... ... (thinks). Then (file on 43; rubs; file on 4; rubs; compares 43 and 4; shakes his head; looks at paper; thinks ; file on 43 (2x); file on 43 and file on 4). I think I got an idea --I guess-- (writes 4 and 43 in boxes 4 and 5).

Discussion

Interviewer: Now, Sam, when you hear the term "hardness of a mineral" what does that mean?

Sam: How hard it is. How good it's put together. Like how it holds each particle that makes the mineral - holds each particle together like -- if it was a really, soft mineral then you could just go like this (scratcing motion). Then you could see a bunch of little particles here (on the table). But if you took a hard one and did that you wouldn't see nothin-just one or two little specks. And --ah--if you took an in between, you would scratch it and you could get some or you could scratch it and you didn't get some (particles). It could be either one.

Interviewer: What do you mean "either one"?

Sam: It could be -if you took one in between hard and soft, if you scratch it it could leave -- but if you scratched it, it may not leave particles.

Interviewer: Leave what?

Sam: Little particles.

Interviewer: So you look to see if particles come off? Does that tell you anything about the hardness?

Sam: Yes, and you could see if anything like this (steel) would scratch it.

Interviewer: If particles come off of two different minerals, how would you know one was softer or harder than the other? What would you look for?

Sam: By how many come off.

Interviewer: You'd look at the numbers of particles. Is there anything else you'd look at?

Sam: How big the particles are. Big particles may mean that it isn't that hard but if there are little particles it may mean it's fairly strong - and only little particles come off and it stays together.

Interviewer: That's what you mean by "strong"?

Sam: Yah -- like it's really hard.

Interviewer: And, you showed me you were going to do something with the steel plate. How would that help you?

Sam: To see if an edge of this (steel) would be able to dig into the rock and take particles out -- like scratch it.

Interviewer: Scratch? Does that (hardness) mean anything else other than scratching or how it's put together?

Sam: How it cleaves.

Interviewer: What do you mean "cleaves"?

Sam: Breaks like um-- if a rock is really hard-- really, really hard-like really strong or narrow or whatever and you hit it with a hammer it may be really hard so it shatters or it may break down the middle or it may not break at all.

Interviewer: And is that cleaving, breaking?

Sam: Yah, if it breaks into even pieces it's cleavage. But, if it shatters it doesn't - isn't cleavage.

Interviewer: So, cleavage can help you tell hardness?

Sam: No, I don't think so.

Interviewer: I see. You mentioned scratching, breaking and cleavage.
Did you use any of them to help you determine the hardness?

Sam: Scratching, just scratching.

Interviewer: How come just scratching?

Sam: Cause to see which would scrated more and which would scratch less. Like if you took a penny and you scratched it with a mineral and it didn't, and you took it and scratched it on a plate and it scratched it, you took it to the file and the file scratched it and the file would be the end of the line for it. It wouldn't be able to go any further. But if you took something it got scratched by the fingernail then it would be farily soft. And if it didn't scratch the nail that would mean that it's kinda soft and kinda hard and in between.

Interviewer: I noticed you used some of these pieces of equipment but not all of them.
Did you use the file?

Sam: Yup.

Interviewer: How did you use it?

Sam: Scraping it with the handle.

Interviewer: And what did that tell you? What were you looking for?

Sam: To see if the file would scratch it.

Interviewer: And what would that tell you?

Sam: That if you took it farther to the glass it wouldn't be able to scratch it.

Interviewer: But supposing the file scratched it. What would that tell you about the mineral?

Sam: That the file is stronger than the mineral?

Interviewer: What do you mean "stronger"?

Sam: It's harder.

Interviewer: And the streak plate?

Sam: I didn't use it.

Interviewer: How come?

Sam: I didn't really have to use it.

Interviewer: Why?

Sam: I don't know.

Interviewer: Does that (streak plate) help you to determine hardness?

Sam: Not really.

Interviewer: How come?

Sam: Well it would help you if you took one mineral and you scratched it and it left something and you took another mineral and it didn't leave anything you could tell which was the hardest -- the one that didn't leave anything is the hardest.

Interviewer: I see. So you might be able to use the streak plate?

Sam: Yah.

Interviewer: And the steel. How did you use that?

Sam: I took the rock and I scratched the steel and then I used the steel to scratch the rock.

Interviewer: And what did that tell you?

Sam: If the rock would scratch the steel, or the steel would scratch the rock.

Interviewer: What do you know then? Supposing the rock scratched the steel. What would you know then?

Sam: That the rock is harder than this (steel) so you would go on to the file.

Interviewer: And the hammer? I noticed you didn't use that - why?

Sam: Cause I didn't have to cleave nothing - like to break it to see -- like what I used was o.k. I didn't need it.

Interviewer: You didn't need it but could you use that as a test?

Sam: Yah. To see if it would cleave.

Interviewer: When would you use it? You said you didn't have to use it for these minerals. How come you didn't have to use it?

Sam: -----(Thinks). Cause um -- these one they could scratch it - my finger nail and this (steel) and this (copper coin) and this (file) could scratch it but I don't know if I had used that (hammer) what I would have used the information for.

Interviewer: And the magnet. Did you use that?

Sam: No, because I didn't have nothing that could be magnetized -- like magnetized. I don't know what I would have used it for.

Interviewer: Does being magnetized help you to know the hardness?

Sam: Not really.

Interviewer: And the penny?

Sam: To see if the penny would scratch it (rock) or if the rock would scratch it.

Interviewer: And the magnet?

Sam: Didn't use it.

Interviewer: How come?

Sam: I didn't have to look at nothing small.

Interviewer: Can you tell me how the hardness scale works?

Sam: Yah. Well, the fingernail is the softest. The copper coin is the second softest and the piece of steel is the second hardest and the file is the hardest.

Interviewer: How would you prove to me that the copper coin is harder than the finger nail?

Sam: Cause you take the penny and take your finger nail and try and scratch it and it doesn't work but if you took the penny and do like this (scratches fingernail) - it scratched your fingernail.

Interviewer: Do you think the hammer should be on the list?

Sam: No.

Interviewer: Why not?

Sam: Because why would you cleave something? Just to see how hard it is? I don't think it would.

Interviewer: But before when you were telling me about hardness you told me it had to do with scratching, cleaving and breaking. How would you get something to break?

Sam: Use a hammer.

Interviewer: When would you decide to use the hammer? How would you know "now is the time I should try and break it"?

Sam: When there is nothing else to do.

Interviewer: Like when this hardness scale doesn't work?

Sam: Yah, when none of this works then you try the hammer and you break the rock and then you break the rock to see what cleaves better.

Interviewer: So the hammer test might come after you did this?

Sam: Yah.

Interviewer: O.k. Now briefly tell me how you decided on this order. You said 7 was the first. How did you decide that?

Sam: Cause I just picked it up and did like this (scratches it) and some pieces came off.

Interviewer: What did that tell you?

Sam: It's the softest cause look you can just go like this (bends 7).

Interviewer: What are you doing?

Sam: Bending it. It's a really soft mineral.

Interviewer: How did you decide that 40 was next?

Sam: Because it was scratched by the penny. Cause I found one straight piece and then I just took it and the penny scratched it, but this can't scratch the penny.

Interviewer: I see. And 28 was the third. How did you decide that?

Sam: Well, this was a tough one. See, I took the penny and it looked like it scratched it, but it didn't. It took part of the penny.

Interviewer: Oh, that's part of the penny on there?

Sam: Yah, some of the copper stuff.

Interviewer: Now, does that tell you anything when it leaves some stuff on there?

Sam: That the penny is softer. Part of the penny came off. But when I went to put it down on the steel and rubbed it a little, it doesn't scratch it very much.

Interviewer: Show me.

Sam: (Steel on 28). You take it and scratch it. It looks like it scratched it.

Interviewer: Does it come off?

Sam: No-----looks like it.

Interviewer: Did you scratch the steel?

Sam: (28 on steel). It cuts it -- better than before.

Interviewer: Maybe you had the steel too far away before. What do you think that means?

Sam: That this (28) is harder. Maybe I made a mistake. (28 on steel again). I guess I was wrong. This (28) is harder. I'll try this - (file on 28) -- scratches and looks (scratches again). I think this the hardest (28).

Interviewer: Why?

Sam: Because the file doesn't scratch it.

Interviewer: So you might change the order?

Sam: Yah from this one to that one (28 should be in the last box).

Interviewer: O.k. just change it below. (He does so). How about 43 and 4 - how did you figure those out?

Sam: It was kind of a draw. It was hard to figure cause the file scratched em and they didn't scratch this (steel). (43 on steel). So this one (43) is where 28 was (on paper i.e. boxes) and this one (4 on steel) scratched it.

Interviewer: What does it tell you about 4 if it scratched the steel?

Sam: This (4) is harder (than steel).

Interviewer: And what does it tell you about 4 compared to 43?

Sam: It's harder.

Interviewer: How come?

Sam: Cause this (4) scratches the steel but this (43) doesn't. Then (file on 4) and this (file) scratches this (4). So this (4) is in the right place but this (43) is in the wrong (place).

Interviewer: So what would you do?

Sam: (Writes 43 below third box).

Interviewer: So you'd just switch those two around?

Sam: Yah -- so that's the ones I got wrong.

T8/10

Interviewer: Now Sandy, supposing your're out in the mountains and you found five minerals-----. Can you do that without using any equipment?

Sam: Pretty hard.

Interviewer: Why?

Sam: Cause you wouldn't be able to see if it scratches it or nothing. You could tell if this was the softest (bends 7) cause you can break it, so you put that down there (puts 7 aside), but these ones would be pretty hard.

Interviewer: Is there anything you could do?

Sam: (Lines up four remaining minerals). I don't think so (studies them)---besides putting these in a sack and taking them back to the city.

Interviewer: No, you can't take them back. You just have the minerals and you say, "I just want to put these in order of hardness even though I don't have any equipment.

Sam: All you could do is just look at them and guess (picks up 43 and squeezes it).

Interviewer: What are you trying to do now?

Sam: See if it would break or something. Just take it and go like that (tries to "break" rest of minerals). But, they're all pretty hard. This (28) looks like it's a harder mineral than the others -- cause it's darker.

Interviewer: What does darkness have to do with hardness?

Sam: Sometimes when a mineral is really (dark), it is strong.

Interviewer: The colour has something to do with it?

Sam: Sometimes-----.

Interviewer: Can you think of anything else you could do besides breaking them with your hands?

Sam: I can't think of anything. That's all you could do.

June 6, 1977

Hardness

Chuck

Interviewer: (Gives directions)

[Minerals: 7-Talc, 40-Halite, 43-Fluorite, 4-Apatite, 28-Corundum.]

Chuck: (File on 7, 43, 28, 4, 40 (doesn't rub off) 1-2times; puts 28 aside; file on 7; file on 43; file on 4; file on 7; file on 40 aside next to 28.) Does this start from soft or hard to soft?

Interviewer: Soft to hard.

Chuck: (Places 7 aside first (to his left); 28 is nearby.
File on 4, file on 43. Puts 4 next to 7; picks up steel; steel on 40. Takes streak plate; 7 on streak plate rubs off; feels (rubs 7) and smells it.
Scratches 7 with fingernail. Tries magnet on 7, 28, 43, 40; looks at 7 with magnifier.
28 on streak plate; 28 on steel; 4 on steel; 43 on steel; 40 on steel; rubs off;
looks at 40; tries again file on 40; file on 28; file on 4;
40 on streak plate; 4 on streak plate 43 on streak plate 28 on streak plate; puts 4 aside (near 7).
File on 40; file on 43; file on 28; scratches once and then files each one once;
Puts 40 next to 4.
Tries magnet on 28 and 43 (the remaining two).
Copper coin on 43; copper coin on 28.) This one (28) leaves a shine when you scratched it with a coin.

Interviewer: Oh.

Chuck: (43 on streak plate; 43 on steel; 28 on steel; puts 43 next in order and 28 last: lines up minerals in from him and writes: 7,4,40,43,28 in boxes.)

Discussion

Interviewer: What does "hardness of a mineral" mean?

Chuck: It's hard----------um-----

Interviewer: What do you mean by the word hard?

Chuck: Hard to scratch.

Interviewer: Hard to scratch------ anything else?

Chuck: Hard to chip.

Interviewer: Chip------.

Chuck: It's pretty hard to break with a hammer.

Interviewer: Break with a hammer-----Is there a difference between chipping and breaking?

Chuck: Chipping --there's just little pieces chipping off (chipping motion with fingers on 40).

Interviewer: If two minerals had little pieces chipping off, how would you know which one was harder?

Chuck: -------- (long pause)

Interviewer: Supposing these two (40 and 4) left little chips around. How would you known which was harder, 4 or 40?

Chuck: I would break it and see which chips more. If you break that (40) and it hardly chips and if you break that one (4) and it falls into crumbs and everything.

Interviewer: So, would you look at the size of the chips, how big they are, or what would you look at?

Chuck: How big they are.

Interviewer: Supposing 40 left bigger chips than 4, what would that tell you?

Chuck: That it chips easier.

Interviewer: Because they're bigger----.Anything else that hardness can mean?

Chuck: It's not magnetic.

Interviewer: What does that tell you about the hardness?

Chuck: It would pick up the rocks with a magnet.

Interviewer: Does that help you know the hardness?

Chuck: No.

Interviewer: It doesn't?

Chuck: Not really.

Interviewer: Anything else hardness can mean?

Chuck: So hard that it would scratch a penny and leave marks (scratches 7 on copper coin) like if you scratch it with something else and it doesn't scratch, it's not very hard.

Interviewer: I noticed you used a lot of the equipment up here. Did you use the streak plate?

Chuck: Yah.

Interviewer: And what where you trying to find out?

Chuck: Which is the softest.

Interviewer: And did it tell you anything?

Chuck: Yah, (points to 7).

Interviewer: How did you know?

Chuck: (Picks up 7 and streaks the plate.) It leaves so much stuff.

Interviewer: How did you know then that 7 was softer than 4?

Chuck: You could break it with your hand (demonstrates).

Interviewer: You can break it----.

Chuck: And this one (4) I can't. It doesn't chip. (tries to break 4 with fingers; streaks 4 on streak plate). And this one (7) had, had-- I smooth off the streak plate like that (rubs off) and this one (4) (tries with more force) left a harder streak (darker - more of a streak).

Interviewer: A harder streak? I see, and you used the piece of steel did you? What did that help you to decide?

Chuck: Well, it left a mark in there (4 on steel).

Interviewer: What did that mean if 4 left a mark on there?

Chuck: It's harder.

Interviewer: What's harder?

Chuck: The rock.

Interviewer: What's harder, the rock or the steel?

Chuck: The steel.

Interviewer: How do you know the steel is harder?

Chuck: If you took a hammer (takes it) and hit it like that, you couldn't break it (shows with a motion).

Interviewer: I see, but 4 can still leave a mark on the steel?

Chuck: Yes and so can this (steel on 4 -3X and rubs).

Interviewer: And you used the coin. What did that tell you?

Chuck: It leaves a mark on the black one (copper coin on 28 and 4).

Interviewer: You told me that this -- it left a shine on 28 (points to 28) What is the shine?

Chuck: The copper coin.

Interviewer: Which is harder, the coin or the rock?

Chuck: ------the coin.

Interviewer: How do you know?

Chuck: Well, it's harder to bend the coin (bends the copper coin with fingers) than the rock. If you hit the rock with a hammer it will crack, but if you hit the coin it will just leave some marks.

Interviewer: I see. You can tell by using a hammer.

Chuck: Yah.

Interviewer: And the file? Did you use it?

Chuck: Yah.

Interviewer: What did that tell you?

Chuck: (File on 28) I tried with this end and it doesn't leave a mark on this one (28) cause it's so hard.

Interviewer: What's so hard?

Chuck: The rock. And this one (4) scratches (file on 4). The rock's too soft. Nope--the rock's is too hard. It doesn't leave a mark in the rock.

Interviewer: Which is harder? It didn't leave a mark on 4 or 28. Which is harder?

Chuck: 28.

Interviewer: How do you know that?

Chuck: Cause I can't even cratch it (file on 28 3X).

Interviewer: So, it's more difficult to scratch than 4?

Chuck: Yah.

Interviewer: And this (magnet) didn't help you at all?

Chuck: No.

Interviewer: And the magnifier . You were studing some of these sometimes. What were you looking for?

Chuck: With this (7)?

Interviewer: What were you trying to see?

Chuck: It looks like a crater - It looks clear and a little green here.

Interviewer: And does that help you know the hardness?

Chuck: ------ it's clear------No.

Interviewer: It doesn't ------So, what were you using it for again?

Chuck: Just for looking. It's interesting. It's green--It seems to scratch easily (file on 7).

Interviewer: O.K. and the hardness scale, did you use it?

Chuck: No.

Interviewer: You didn't use it at all?

Chuck: Well, I could scratch it with my fingernail (fingernail on 7) and copper penny (copper coin on 7) and piece of steel (steel on 7; file on 7)....

Interviewer: And what would that tell you?

Chuck: It (7) was all scratched-----the rock.

Interviewer: And what did that tell you about the hardness?

Chuck: It's soft.

Interviewer: Softer that what?

Chuck: Softer that this stuff.

Interviewer: All this stuff (equip)?

Chuck: Except the fingernail. It (7) wouldn't scratch the fingernail.

Interviewer: Could your fingernail scratch it?

Chuck: (fingernail on 7) Yah.

Interviewer: So, would this be on the hardness scale?

Chuck: It's the softest one.

Interviewer: And 4? How did you decide on 4?

Chuck: Fingernail, copper penny, (copper coin on 4), piece of steel (steel on 4), and file (file on 4).

Interviewer: So, how do you know 4 comes second?

Chuck: Cause it's softer than these (points to other minerals). All of these are harder.

Interviewer: And how did you decide 40 was third?

Chuck: I scratched it with this file -----(file on 40) it scratches. And then I scratched it with this (steel). (Steel on 4) It scratched with that. (Copper coin on 40) It chips! (Pieces fly off on to the floor.)

Interviewer: How do you know 40 is harder than 4?

Chuck: Cause of this (picks up chips).

Interviewer: The chips?---- Could you think of something you could do to prove 4 was harder than 40?

Chuck: You hit it slightly and see how it crumbles--which crumbles first.

Interviewer: You hit it lightly?

Chuck: Yah, just tap it evenly and which crumbles first is the softest.

Interviewer: I see------.

Chuck: Hit 4 once and 40 once (does so). This one's (40) softer.

Interviewer: That one is softer. So what would you do here (order on paper).

Chuck: Change them (picks up pencil to write). [Willing to change answer in light of new evidence]

Interviewer: OK, put it underneath. Make a new row. All right, how do you know 43 is harder than 40?

Chuck: I can tell by feeling (feels 43 and 40; presses them).

Interviewer: How can you tell by feeling?

Chuck: It's hard. (Picks up 43) It's clear.

Interviewer: What does clearness tell you about being hard?

Chuck: (Looks; tries to chip 43 with fingernail's; picks up hammer.) Maybe this is hard. Maybe I can chip it. (Taps 43 once) 40 is softer.

Interviewer: And how do you know 28 is the hardest of all?

Chuck: (Picks up 29) Well I could tell that------.

Interviewer: How?

Chuck: Well, I hit it and it doesn't chip (does so with hammer; hammer on 43). Maybe I can scratch it. (File on 28; file on 43; rubs and examines) See the scratch. (Copper coin on 28) You can tell that's harder cause it just takes the mark off of here (off of copper coin); (copper coin on 43 ------.

Interviewer: It doesn't on 43?

Chuck: No.

Interviewer: So you're still saying that 28 is harder. So these (40 and 4) are the only ones you'd switch around then?

Chuck: Yah.

Interviewer: Supposing you were out in the mountains and found five minerals-------. Could you do it?

Chuck: -------(Looks at minerals; picks up 43 and pounds it on the table.)

Interviewer: Can you think of what you might be able to do?

Chuck: Get another rock (hits 4 with 43).

Interviewer: You don't have another rock. You just have these (the minerals).

Chuck: -- ----------

Interviewer: Well, supposing you had another rock. How would you use that?

Chuck: Smash it.

Interviewer: Supposing you didn't have another rock, just these five minerals.

Chuck: -------------

Interviewer: Could you find the softest one?

Chuck: (Picks up [illegible]

Interviewer: How could you know that?

Chuck: It scratches (scratches 7 with fingernail; fingernail on 28, 4,43,40).

Interviewer: Could you find the difference between these four (28,4,40,43)?

Chuck: (Picks up 43 and taps it; turns it around; looks at 4; 4 on 40; 4 on 28; 4 on 43.) Makes a mark.

Interviewer: Does that tell you anything?

Chuck: It's softer.

Interviewer: What is softer?

Chuck: (Picks up 4 and indicates it).

Interviewer: This one (4) is softer than 43?

Chuck: (4 on 43 again; 43 on 4; looks at them) Scratches.

Interviewer: So you can scratch 4. Then where would that come in the order?

Chuck: (Puts 4 next to 7)

Interviewer: What would come next?

Chuck: ---------

Interviewer: How would you decide between these three-43,40 and 28?

Chuck: ---------(picks up 40) Well, this one looks like it's got a chip (chips with fingernail and puts it down).

Interviewer: What would you do with 40 then?

Chuck: (Puts 40 next to 4(7,4,40)) No, I'd trade it (40) around with this one (4). So, 7,40 and 4.

Interviewer: Why?

Chuck: Because that one (40) I can chip with my fingernail and that one (4), I can't.

Interviewer: And next?

Chuck: (Picks up 28; tries to chip with fingernail; puts 28 to his teeth.)

Interviewer: And you going to bite it? (concerned with safety and teeth here)

Chuck: Nope.

Interviewer: Your poor teeth! On, your're trying to chip it with your teeth?

Chuck: (Puting 43 to his teeth- behind upper front teeth and stroking outward). This (43) is the softer one. (Repeats with 43 and 28; compares them. This leaves a little mark (on 43). [Scratching with his teeth]

Interviewer: 43 leaves a little mark on your teeth?

Chuck: Yah.

Interviewer: Let's record this order now: 7,40,4,43,28. You came out with the same order as last time. What do you think is the more accurate way, what you did last time or when you used all the equipment?

Chuck: What do you mean?

Interviewer: Well, first you determined the order using all kinds of equipment. Down here (order 2) you just used the minerals themselves to determine the order. Which method do you think was better, to use the minerals alone or to use the equipment?

Chuck: Well, you can find out more things using the equipment.

Interviewer: Why?

Chuck: Well, you can scratch and if you had the hammer you can hit it.

June 6, 1977

Hardness

Tim

Interviewer: (Gives directions)

[Minerals: 7-Talc, 40-Halite, 43-Fluorite, 4-Apatite, 28-Corundum.]

Tim: (Hammer on all minerals) This is easy. I know what it (7) is.
I'm testing the hardness (hits each mineral in turn).
(Picks up file; file on 7, 4,43,28, and 40.)
That's (7) weak. Magnet on 7,4,43,28,4; uses magnifier to look at each; magnet on 7,4,43,28,40; then copper coin on 7 and writes; copper coin on 4,43,28, and 40; then steel on 7,40,28,4,43; writes; puts 7 aside and 40 aside.
28,4,43 on streak plate.
Hammer on 4, 43,28; looks at them; hammer on 43,4 again; then file on 4 and 43; bends 4, steel on 43,4,28 and writes.)
(Works quickly; doesn't rub off.)

Discussion

Interviewer: What does "hardness of a mineral" mean to you?

Tim: Well, how tough it is (bends 7 back and forth).

Interviewer: What do you mean "tough"?

Tim: Well, if you took a steam roller and ran over it and it was this one (28) and nothing happened and then you took another rock the same size like this (43) and ran over it and it crushed, then this (28) would be harder because it stood more pressure.

Interviewer: So, how easily it breaks? Does it mean anything else besides breaking?

Tim: Hah, how tough it is on the outside. If I put this (28) in an oven and raised it all the way up to 2000 F, and this came out - it came out a bit melted and I put this one (43) in and it melted all to the ground, then I would say this one (28) was harder and tougher because of the degrees.

Interviewer: It's tougher on the outside. Do you think the inside is just the same as the outsdie or something different?

Tim: Well, if we pretend this substance (43) had this (28) on the inside and you melted it, it might just stay a little longer there.

Interviewer: Ok. Does hardness mean anything else besides melting, breaking, and toughness?

Tim: --------Can't think of any.

Interviewer: I noticed you used some of the equipmet up here. Can you tell me how you used each piece? The hammer?

Tim: Yah, so I could see how things broke down. If I pounded this one (pounds 40) --it breaks real easy and if I pound this one (28), it doesn't break as fast.

Interviewer: What do you mean "break as fast"?

Tim: Chip away (hammer on 40 again).

Interviewer: Supposing this one (40) chips and 43 doesn't chip?

Tim: (Hammer on 43) Yah.

Interviewer: Now, they both chipped. How do you decide which one is harder?

Tim: Well, you could tell by seeing--- and use the copper coin.

Interviewer: Well, what about the hardness? What does it tell you?

Tim: Well, not really. It can give you a general description.

Interviewer: What do you mean?

Tim: Well, this one (40) breaks away pretty fast (hammer on 40 and hammer on 43). It (43) doesn't break away as fast on 40-- it's softer.

Interviewer: So the hammer helps you tell hardness. And the magnet?

Tim: I used it to see if they were magnetic and if they were magnetic then they would be as tough as this magnet then.

Interviewer: Did you use the magnet?

Tim: Well, I went like this (magnet on all minerals) and nothing happened.

Interviewer: And the magnifier?

Tim: Well, I chipped it away and this I used it to zoom in-to close in. They were both even and I looked to see if this one (40) chipped a lot and this one (43) didn't chip very much and I could tell this one (43) was harder.

Interviewer: And the steel?

Tim: Yah--- you tell (steel on 7)--look! This is so easy, but (the surface) this one (28) is a real lot harder.

Interviewer: And the file. What did that tell you?

Tim: By scraping it---gave me a way---how tough the surface is.

Interviewer: What do you mean "tough"?

Tim: Well, you could roll a steam roller over it and break it with a hammer and put it in an oven at 3000 F and it came out the same, it would be a tough mineral.

Interviewer: And the streak plate? Did you use it?

Tim: No. (He did use it.)

Interviewer: Could it help to determine the hardness?

Tim: Well--yah. (7 on streak plate) This (7) would --no sweat. And (4)-nothing happens.

Interviewer: What does that tell you about 4 and 7?

Tim: 7 is a lot softer.

Interviewer: How come?

Tim: I just go like that (7 on steel streak plate) and it comes off.

Interviewer: What do you look for?

Tim: How fast--if it leaves a mark it means it's sort of softer.

Interviewer: O.K. But you didn't use this (streak plate) very much. How come?

Tim: Must have forgot, I----

Interviewer: Now, can you tell me how you decided on this order? How did you know 7 was the softest?

Tim: Well, cause it's--- look at that (bends it).

Interviewer: What are you doing now?

Tim: Well, it's so easy to bend (keeps bending it).

Interviewer: And 40?

Tim: It's sort of like wax (hammer on 40 again).

Interviewer: You pounded it and that's how you knew?

Tim: Yah-- it chips away faster than these three (28,43, and 4).

Interviewer: And 4?

Tim: Cause it's (uses file to hit 43 and 4)-this one's (4) sort of got a weaker surface than this (43).

Interviewer: So, you banged it to help you tell the difference?

Tim: Yah.

Interviewer: And 28?

Tim: Same. (Hammer on 28) See----(hammer on 43 and 4) 43 chips away more than 4.

Interviewer: What's the difference between these two (28 and 4)?

Tim: I think I made a mistake.

Interviewer: How come?

Tim: Well, 28 should --- see this one (43) broke away and this (28) didn't as much. (Hammer on 28 and 4 and compares again, then, changes order on paper).

Interviewer: Supposing your're out in the mountains and you find five minerals, --------. Could you do it? Oh, did you use the hardness scale at all?

Tim: Nope.

Interviewer: How come?

Tim: I wasn't paying attention to it. I was mainly trying all the things (equipment).

Interviewer: And the copper coin? Did you use it?

Tim: Yah, it scraped a little --just like file.

Interviewer: I see --- back to the mountains now. (Repeats problem) Could you do it?

Tim: Maybe you could throw it on the ground and see what happends.

Interviewer: And what would that tell you?

Tim: If I threw it on the ground and one big piece was there, I could say it (7) was pretty hard. And if a little piece chipped away (4), I could say it was harder than that (4 harder than 7). And if I threw this (28) and nothing happened I would say this was the hardest of all. And (if I) threw this one (43) and some broke off and then I threw this (40) and some chipped, I could tell you - you know.

Interviewer: Supposing you couldn't throw it. Is there anything else you could do?

Tim: Stamp on em real hard.

Interviewer: Anything else?

Tim: Bash another rock against this rock (4 on 7). And then if I bash this on (4 and 40), it chips and things came out of that----.

Interviewer: Can you do anything besides hitting one rock on another?

Tim: Um-----------------maybe bite it.

Interviewer: How would you know by biting which was harder?

Tim: Well, if this one (7) snapped in half I would say this was pretty soft. And if I bite this (28) and nothing happens and this-- I bite this (43) and a little comes off -----and-----

Interviewer: Supposing you bit two of the minerals and nothing happened. How could you tell which was harder (i.e. 28 and 4).

Tim: I'd have to maybe stamp on it.

Interviewer: Try another test? Can you think of any other tests?

Tim: ------------Um---------No, I can't think of any other tests.

June 7, 1977

T11/1

HARDNESS

Roy

Interviewer: (Gives directions)

[Minerals: 7-Talc, 40-Halite, 43-Fluorite, 4-Apatite, 28-Corundum.]

Roy: (Feels all minerals with fingers-a back and forth rubbing motion-not scratching; writes 7 in box (Box 1).
File on 4,40,28,43 and writes (40 in Box 2).
Feels 43 and 28; 28 on steel; 43 on steel; 4 on steel; writes (Box 3-#4).
Feels 40; thinks; feels 28; 28 on copper coin; 43 on steel; 28 on steel; writes in boxes.
Looks at 28. (Box 4-#43) (Box 5-#28).
(Doesn't look at hardness scale.)

Discussion

Interviewer: What does "hardness" mean? When you hear the words "hardness of a mineral" what do they mean?

Roy: Well, you can scratch and tear it and it's hard and you can break it.

Interviewer: And besides scratching and breaking it, is there anything else?

Roy: -----------(long pause)-----------

Interviewer: Is that about it? Scratching and breaking?

Roy: Yah, that's about it.

Interviewer: Now, Roy, I noticed you used a number of these objects. Did you use the magnet?

Roy: Yes (picks up magnet).

Interviewer: How come you used it?

Roy: I wanted to see if it's magnetic.-- I don't ---------

Interviewer: Will that help you find the hardness?

Roy: No.

Interviewer: How come?

Roy: It just shows if its magnetic.

Interviewer: I see. And the streak plate? Did you use that? (I reaches for streak plate)

Roy: (Touches streak plate) No.

Interviewer: How come?

Roy: Well, it's used for what color it shows.

Interviewer: And will that help you to find the hardness?

Roy: No.

Interviewer: And the hammer? You didn't use it. Will that help you find the hardness?

Roy: Yup.

Interviewer: It will? How ccme you didn't use it?

Roy: --------- cause I--um ---- I'm not sure why I didn't use it.

Interviewer: And the little steel? Did you use that?

Roy: Yup.

Interviewer: How come you used that?

Roy: Well, to see if it could scratch it - to see if it's hard or not.

Interviewer: If it's hard or not?

Roy: To see if the rock is hard or not.

Interviewer: Supposing you scratched 40 on that. Did you use 40?

Roy: No.

Interviewer: How about 4?

Roy: Yah.

Interviewer: What happened?

Roy: It made a scratch.

Interviewer: And what did that tell you?

Roy: It's harder.

Interviewer: What's harder?

Roy: The rock.

Interviewer: Which is harder, 4 or the steel?

Roy: The steel.

Interviewer: How do you know that?

Roy: Cause the steel can't break as easy. It can't ----.

Interviewer: And the copper coin? Did you use the copper coin?

Roy: Yah.

Interviewer: And what happened?

Roy: It scratched it or not.

Interviewer: And when it so scratched it, what did it tell you?

Roy: That it's harder.

Interviewer: What was harder?

Roy: The rock.

Interviewer: The rock was harder than what?

Roy: The penny.

Interviewer: And the file? Did you use the file?

Roy: To see if I could make a mark on the rock.

Interviewer: And what did that tell you?

Roy: If the rock is harder than the file.

Interviewer: And did you use the hardness scale?

Roy: Nope.

Interviewer: You didn't use any of these?

Roy: (Looks at hardness scale; points to it with pencil) I used the file and the piece of steel and the copper penny and not the fingernail.

Interviewer: You didn't use the fingernail. O.K. which is harder, the copper coin or the piece of steel?

Roy: --------piece of steel.

Interviewer: Could you prove that to me?

Roy: ------- --------- -------

Interviewer: What could you do to prove that the steel was harder then the penny?

Roy: (Takes 43 and scratches penny and then 43 on steel) Well, you could scratch this one (43 on copper coin) and see if it makes a mark. (It does.)

Interviewer: Yes-----

Roy: And then see if it makes a mark on this one (steel).

Interviewer: Did it make a mark?

Roy: Nope.

Interviewer: What does that mean?

Roy: That this (steel) is stronger than the penny.

Interviewer: Supposing you only use the copper coin and the steel. Could you still prove that the steel was harder than the copper coin?

Roy: um------- (looks at both)---------

Interviewer: Could you do something to prove the steel is harder than the copper coin?

Roy: Can I use anything else (indicating other objects)?

Interviewer: Nope, use those two.

Roy: I could see if this (copper coin) on this (steel). (Does it.) Nope.
(Steel on copper coin and rubs off each time)
This one does (steel scratches coin).

Interviewer: So, which is harder?

Roy: This one (point to steel).

Interviewer: O.K. In the order here you said that 7 was the softest. How did you decide on that?

Roy: (Picks up 7 and bends it and thumbs the edges) Well, it feels like you can break it easily and it's soft.

Interviewer: That's the test you did on that? (Pause) And how did you decide 40 was next?

Roy: (Picks up 40) Well, it isn't strong enough to scratch the glass.

Interviewer: To scratch what glass (none on the table)?

Roy: I mean not the glass (40 on steel), steel.

Interviewer: The steel?

Roy: Yah.

Interviewer: And 4 was next. How did you decide 4 was next?

Roy: (Picks up 4 and feels it using a bending motion; then scratches 4 on steel.) Well, because this is soft.

Interviewer: It's soft?

Roy: Yah, and it scratches this (steel). (Scratches 4 on steel.)

Interviewer: How do you know that this (4) is harder than 40?

Roy: (Picking up file; file on 4) This leaves a mark and on here it goes in better on 40.

Interviewer: Oh yes, it goes in better with 40. And 43 was next (4th). How did you decide on that?

Roy: Well, I took these two (43 and 28) and 28 on steel) and I rubbed it like this and this one couldn't scratch this. 28 could, so I put 43 next and 28 last.

Interviewer: Did you do any other tests on them?

Roy: No.

Interviewer: O.K. one more question. Supposing you are out in the mountains and you don't have any of this equipment along. You find these five minerals and you sit down and think. "I wonder if I can put these in order of increasing hardness even if I don't have any of this equipment here. Do you think you could do that?

Roy: Well, you could feel it and (picks up 7 and scratches with fingernail) and then see if they scratched (4 on 7) and scratch.

Interviewer: Scratch each other? Which one is the softest?

Roy: 7.

Interviewer: O.K. and then what would you do with the rest of them?

Roy: Scatch them. (43 on 4; 43 on 28; 43 on 40; scratches 40 5-8X and rubs off; looks and places 40 next to 7.) This (40) goes next to 7.

Interviewer: How did you know that?

Roy: Cause it scratches and there's less scratches (points) and this (28 and 4) doesn't scratch good. And it scratches better (43 on 40).

Interviewer: And how about the last three. How would you decide between those?

Roy: (43 on 4; 43 on 28-2X and rubs off.)

Interviewer: With 43 and 28 --what happens when you rub it off?

Roy: It doesn't leave a scratch.

Interviewer: What does that tell you? Does that tell you anything?

Roy: It's softer. (Puts 28 next to 40; tries 4 on 43 and rubs.)

Interviewer: Try the other side of 43.

Roy: (Scratches and rubs off) Scratches.

Interviewer: What does that tell you?

Roy: This (4) rock is harder.

Interviewer: 4 is harder than what?

Roy: 43.

Interviewer: So, where would you put 43 in the order?

Roy: 43? (Puts 4 next to 28: (7,40,28,4).) Right here (next to 4).

Interviewer: So, you're saying that this (7) is the softest: then this one (40) and then 28 is next hardest and then 4, and 43 is hardest of all. Now this order (last one) is a little different from this one (first order). Which do you think is more accurate?

Roy: This one (bottom).

Interviewer: The bottom one - how come?

Roy: Well, I did different things.

Interviewer: What do you mean different things?

Roy: Well, I tried to see if it would scratch.

Interviewer: Why is that a better test than using this equipment?

Roy: Well, you can see which one is harder.

Interviewer: Look at 28. Here it is in the middle and here it is at the end. You think this (bottom is more accurate than this (top)?

Roy: Yah.

June 7, 1977

Hardness

Nan

Interviewer: (Gives directions)

[Minerals: 7-Talc, 40-Halite, 43-Fluorite, 4-Apatite, 28-Corundum.]

Nan: (43 on streak plate; puts streak plate aside; fingernail on 43; picks up copper coin and scratches 43; rubs off; 43 on copper coin; puts copper coin aside. Steel on 43 and 43 on steel; rubs and blows; puts steel aside. File on 43-(2X); writes 43 on paper; steel on 43 and 43 on steel; fingernail on 4; copper coin on 4 and 4 on copper coin; 4 on steel and steel on 4; writes (second line). Fingernail on 7-(2X) and writes (3rd line).
Fingernail on 28-(2X); copper coin on 28 and 28 on copper coin. 28 on steel and steel on 28-rubs. File on 28 rubs; thinks; 28 on streak plate (1X); writes (4th line).
Fingernail on 40; 40 on copper coin and copper coin on 40; writes (5th line).
Studies (reads observations) and fills in boxes.

Discussion

Interviewer: Nan, when you hear the words "hardness of a mineral" what does that mean to you?

Nan: I don't know - how hard.

Interviewer: What do you think of when you say "how hard it is"?

Nan: Well, how it scratches.

Interviewer: How it scratches ---- Could it make anything else?

Nan: How easy it breaks.

Interviewer: Anything else?

Nan: -------No--------

Interviewer: What's the difference between breaking and scratching?

Nan: Well, when you break it you pound it and when you scratch it you --scratch it.

Interviewer: What do you look for? Is there any difference in what you see?

Nan: Well, when you break it, it's usually in a bunch of pieces.

Interviewer: How does that help you decide the hardness - when you break something?

Nan: Well, how easy it breaks --how hard you have to hit it before it breaks.

Interviewer: Do you ever look at anything else -- the number of pieces that come off?

Nan: Yah.

Interviewer: And what do you look for in scratching?

Nan: Um, how easy it scratches with certain things.

Interviewer: What do you mean "how easy"?

Nan: Well, like if you can scratch it real easily with steel ----

Interviewer: Or your fingernail?

Nan: Yah.

Interviewer: Can you tell me what objects you used to help you decide on the hardness of the minerals?

Nan: File, penny and steel and fingernail.

Interviewer: And the scale?

Nan: Yah.

Interviewer: What does the scale tell you?

Nan: Well, like, um, like if you scratch something with your fingernail it would be very soft and with the file it would be hard.

Interviewer: You mean the file is harder than the fingernail?

Nan: Yah.

Interviewer: How could you prove that to me?

Nan: Scratch my fingernail with it.

Interviewer: Try it and see what happens. Is it true?

Nan: (Does so; file on fingernail.)

Interviewer: Does it scratch?

Nan: Yah.

Interviewer: Could you prove that the steel is harder than the penny?

Nan: Yah.

Interviewer: How?

Nan: Scratch it.

Interviewer: Let's see if that works.

Nan: (Does so)

Interviewer: Does it (work)?

Nan: Yah.

Interviewer: How do you know?

Nan: It leaves a scratch behind.

Interviewer: How did you decide on this order: 7,40,43,4,28?

Nan: Well, I just worte down the hardest thing they were scratched by and ------

Interviewer: So, with 43, Which was harder, the steel or 43?

Nan: Steel.

Interviewer: (Reading Nan's results) And 4 scratched steel, so what did that tell you?

Nan: Oh.. the rock is hard.

Interviewer: And 7 was scratched by fingernail. What does that mean?

Nan: Fingernail is stronger.

Interviewer: Stronger? What do you mean stronger?

Nan: Well, it breaks or anything or scratches.

Interviewer: Did it break or scratch? So, if either of those two things happened, breaking or scratching, that would tell you something about the hardness?

Nan: Yah.

Interviewer: (Reading from paper) "28 can't be scratched by a file very well".

Nan: It scratches a little bit.

Interviewer: A little bit. What did you conclude from that?

Nan: Well, it's pretty hard.

Interviewer: 40 scratched by penny. Which is harder.

Nan: Penny.

Interviewer: Penny is harder. So from all of this (observations), how did you get this (order in boxes)? (Observation are not in order.)

Nan: I just went from softest to hardest.

Interviewer: Softest to hardest .. Alright, now Nan, supposing you are out in the mountains and pick up some minerals------------. Could you do that? Could you think of a way?

Nan: Use them against each other.

Interviewer: Would you like to try it? Show me what you would do.

Nan: Take 4 and 28 (scratches 4 on 28).

Interviewer: What happened?

Nan: 4 got scratched.

Interviewer: How do you know?

Nan: There's little pieces left on 28.

Interviewer: Which is harder?

Nan: 28.

Interviewer: O.K.

Nan: (4 on 43; rubs; 28 on 43; 4 on 40; rubs.

Interviewer: Anything happen?

Nan: Nope (43 on 40).

Interviewer: Anything happen with 43 on 40?

Nan: Nope. (20 on 40; 4 on 7; 43 on 4 (works quickly)).

Nan: 7,40,43,4,28 (writes down).

Interviewer: That's a little different from your other order. Which do you think is more accurate?

Nan: -----------

Interviewer: Not sure?

Nan: Well, I think the one I did with the tools is more accurate.

Interviewer: Why?

Nan: -----------Well, they all got like ----- (sighs)-----looks --------they got all the tools and the hardness scale so I know which is harder.

Interviewer: Is it easier to tell that way?

Nan: Yah.

Interviewer: So, it's easier to tell that way (tools) rather than this way (scratched against each other).?

Nan: Yah.

Interviewer: But could you get some kind of order this way (scratching) if you didn't have the tools?

Nan: Yah.

Interviewer: But you think it might not be as accurate?

Nan: Yah.

Interviewer: One more thing. You didn't use the hammer?

Nan: No.

Interviewer: You did use the streak plate. What did that tell you?

Nan: To see if it had a little bit of color.

Interviewer: Would that help you solve the problem?

Nan: Not really...Well, the softer the rock-like if a rock is soft, it'll leave little crystals behind and the harder it is-the rock won't scratch.

Interviewer: And did this one (streak plate test) help you at all?

Nan: No

Interviewer: How come?

Nan: The ones that I tried on it didn't leave a mark?

June 8, 1977

Hardness

Darla

Interviewer: (Gives directions)

[Minerals: 7-Talc, 40-Halite, 43-Fluorite, 4-Apatite, 28-Corundum.]

Darla: (File on 28; rubs; 28 on streak plate (2X); 28 on steel (1X); file on 28 (2X); writes on hardness scale; puts 28 aside.
43 on copper coin; 43 on steel; file on 43 rubs; writes.
4 on copper coin; 4 on steel; 4 on streak plate (1X); looks at hardness scale; file on 4; writes.
4 on streak plate; 28 on streak plate puts; 4,28,43 aside.
Picks up 7; fingernail on 7; bends it and writes; puts 7 aside.
40 on copper coin (3X); writes; thinks; takes 7; fingernail on 7; 40 on copper coin; 4 on steel; 28 on steel; looks at hardness scale; file on 28; file on 43.

Discussion

Interviewer: Now, this (discussson) is all about hardness. What do you think of when you hear "hardness of minerals"?

Darla: -----Whether it's soft or hard.

Interviewer: What does that mean?

Darla: ------------

Interviewer: How would you decide if something were soft or hard?

Darla: By testing it.

Interviewer: How?

Darla: The hardness scale.

Interviewer: How does that tell you the hardness?

Darla: ----------- Everything starts going from softer to harder.

Interviewer: What do you mean "everything"?

Darla: That the fingernail is the softest, then the copper coin, then the steel and then the file.

Interviewer: How could you prove to me that the copper coin is in fact harder than the fingernail?

Darla: -------------(picks up 7)-----------

Interviewer: How would that help you?

Darla: Well, this (fingernail) scratches that (7) and (7) doesn't scratch the fingernail.

Interviewer: Supposing you didn't have the minerals, you just had the copper coin and the fingernail

Darla: Well, you can't break it (copper coin).

Interviewer: What do you mean "break it"? [associating hardness with bending/breaking]

Darla: Can't bend it or break it. You can your fingernail.

Interviewer: Any other way you could prove it besides bending or breaking it?

Darla: ----------Scratch it.

Interviewer: What would happen if you scratched it? [Scratching a means of breaking?]

Darla: Your nail would break.

Interviewer: If you scratch it with what?-----Try it.

Darla: (Fingernail on copper coin)

Interviewer: Anything happen?

Darla: No.

Interviewer: Can you do it another way?

Darla: -------Take an object and scratch it with your fingernail and then the penny.

Interviewer: But you don't have an object, you just have your fingernail and the penny.

Darla: ------------

Interviewer: You scratched this (copper coin) with your (fingernail)-----?

Darla: -------Well, I could try this (fingernail) on this (copper coin).

Interviewer: Try it.

Darla: It scraped.

Interviewer: What does that mean?

Darla: So, this is harder (copper coin).

Interviewer: Can you show me what objects you used to help you determine the hardness of minerals?

Darla: Mostly?

Interviewer: Anything at all.

Darla: Copper coin, steel, file, and streak plate once.

Interviewer: And the hardness scale?

Darla: Yah.

Interviewer: How did you use the penny?

Darla: I scratched the rocks on it.

Interviewer: What did that tell you?

Darla: Whether it was softer or harder than it (copper coin).

Interviewer: And how did you tell that?

Darla: By looking at the scratch.

Interviewer: And if it scratched - what did that tell you?

Darla: It's harder.

Interviewer: And if it didn't scratch?

Darla: It's softer.

Interviewer: And the steel?

Darla: If I scratched it with a rock and it wouldn't scratch then it was softer than this (steel). And if the rock could scratch it, the rock was harder.

Interviewer: And the file?

Darla: If the file couldn't scratch a rock, the rock was harder ----------no--------- the rock is softer -- if you can scratch it with a file.

Interviewer: And what did you use the streak plate for?

Darla: To see if some (pieces) would scrape off (using a streak plate).

Interviewer: And what would that tell you?

Darla: If it was softer than this (streak plate).

Interviewer: And would that help you to put it in order of hardness here (hardness scale)?

Darla: Not really.

Interviewer: How come?

Darla: I don't know.

Interviewer: What makes you think it wouldn't?

Darla: ---------You can't see any scratch.

Interviewer: So, did that help you at all?

Darla: No.

Interviewer: You didn't use the magnet, did you? How come?

Darla: You didn't need that for hardness .

Interviewer: And the hammer?

Darla: I didn't need it.

Interviewer: Do you think you'd ever need it to test hardness:

Darla: You might.

Interviewer: When?

Darla: If you got a real hard rock. [When to use a hammer]

Interviewer: And how would tell if it were harder or softer?

Darla: If you kept hitting and hitting and hitting it and it doesn't break, then the rock is harder than the hammer.

Interviewer: Can you tell me how you decided on this order (7,40,4,28,43)?

Darla: By testing with this (hardness scale).

Interviewer: How did you decide 7 was first?

Darla: I tried with my fingernail.

Interviewer: And what happened?

Darla: It (7) scratched.

Interviewer: And 40?

Darla: It wouldn't scratch the copper penny.

Interviewer: Did you test it any other way? How did you know it didn't come first?

Darla: Cause I couldn't scratch it with my finger nail.

Interviewer: And then 4?

Darla: Cause it scratched the steel, but wouldn't scratch it (file). [File does scratch 4]

Interviewer: Show me.

Darla: (4 on steel) It scratched.(File on 4.)

Interviewer: What does that tell you?

Darla: That it's (4) softer than this (file) and (4) is harder than steel.

Interviewer: So, where does it come on the hardness scale?

Darla: After the steel.

Interviewer: And 28?

Darla: You can scratch the steel and when you scratch

this (file on 28) it just barely leaves a mark. You can wipe it off. It just barely scratches it.
You can see the mark (looks with magnifier).

Interviewer: What does that tell you?

Darla: It's just below.

Interviewer: Below what?

Darla: Below this (file). Comes below this (file). (below steel, not file, but places it in the correct place)

Interviewer: And 43? Why is it last?

Darla: Cause you can't scratch it with a file.

Interviewer: Show me.

Darla: (File on 43) See, it just breaks off.

Interviewer: Try again.

Darla: (Does so)----------

Interviewer: O.K.

Interviewer: Supposing your're out in the mountains and you found five minerals ---------. Could you do that?

Darla: (Shakes head) Nope.

Interviewer: How come?

Darla: Cause if it can't scratch the fingernail you wouldn't know if they could scratch something else.

Interviewer: Could you figure out any of these?

Darla: Just this one (7).

Interviewer: Now, you're left with these four. Could you think of anything you could do with them?

Darla: You don't have none of them (equipment)?

Interviewer: No, you left tham all at home.

Darla: ----------Try and scratch these (points to minerals).

Interviewer: What do you mean?

Darla: Scratch them with your fingernail.

Interviewer: That would give you one of them. Anything else you could do?

Darla: ----------You could scratch this rock (43) on this one (40).

Interviewer: What would that tell you?

Darla: Which rock is softer.

Interviewer: Try it.

Darla: (4 on 40) This (40) is softer. (Puts 40 next to 7). Order: 7,40. (43 on 4) This one's (4) softer. (Puts 4 next to 40 (7,40,4); 43 on 28). This one's (28) softer (puts 28 next to 4.) (Final order: 7,40,4,28).

Interviewer: Can you sow me the mark (on 28)?

Darla: You can see a bit in there.

Interviewer: A bit of what?

Darla: Scratch.

Interviewer: Do it again.

Darla: See the scratch?

Interviewer: No, you must have very good eyes (looks with magnifier).

Darla: It's just barely.

Interviewer: I see. What would you do next?

Darla: This (43) would be the hardest.

Interviewer: And what next?

Darla: Try this by scratching each other (28 on 4). This (4) is softer. (28 on 40) This (40) is softer. (Puts 28 next to 43; Order: 28, 43). (4 on 40; and 40 on 4;) Then this one (4) next to

28. (Order: 43,28,4) and then 40 and 7.

Interviewer: So you ended up with the same order as before? Which method you think is more accurate?

Darla: The first one.

Interviewer: Why?

Darla: --------------

Interviewer: Any idea?

Darla: -------------- No. ----------

Interviewer: You just think so?

Darla: Yah.

Interviewer: Let's go back to the beginning when you said hardness could mean scratching or breaking. What is the difference between those two?

Darla: When you break something you try to crack it and if you scratch something you try and rub something on it.

Interviewer: And they both help you to find the hardness.

Darla: Yup.

June 9, 1977

T14/1

Hardness

Penny

Interviewer: (Gives directions)

[Minerals: 7-Talc, 40-Halite, 43-Fluorite, 4-Apatite, 28-Corundum.]

Penny: (Looks at minerals; scratch with thumb; proceedes in order; file on 43,4,7,28,40 (3-5X); works quickly; puts 7 aside (to her left) and works with remaining minerals.
Picks up copper coin; scrapes 4,43,28,40) Ummm. (sets 4 to her right: 7 ----- 43,28,40, ------ 4; Then puts 43 next to 4: 7 ------ 28,40 ----- 43,4; and places 28 next to 7: 7,28,------- 40 ------ 43,4).
Looks at 40; picks up steel and scratches 40 with steel; then scratches 43 and 4; back to 40; puts 4 next to 28, so now: 7,28,4,40 and 43. Looks at 40; puts down steel and picks up file; file on 40; filing; chips come off; files 43, chips come off; puts 40 next to 4; and then 43 next to 40 and ends up with an order of: 7,28,4,40,43.
(4 minutes to complete task)
Begins to write; fills in boxes)

Interviewer: Can you write down how you decided on the order? Use the space in the middle.

Penny: (Writes; pauses now and then; doesn't pick up minerals again and look at them; occassionally points with pencil occassionally to hardness scale on top of paper while pausing). (10 min. to complete write-up).

Discussion

Interviewer: Penny, can you tell me everything you know about hardness of minerals?

Penny: ----------

Interviewer: What does it mean to you?

Penny: Um.......... Generally the hardest is the toughest to break and stronger than the other ones or any other one.

Interviewer: Does it have any other meaning than breaking or strongness?

Penny: ----------

Interviewer: Or are those the main two?

Penny: Yes.

Interviewer: What the difference between breaking and strongness?

Penny: Breaking means it can fall apart easy (making breaking motion with hands) and rocky type you put together. And strongness means it's all one solid piece.

Interviewer: Can you show me one that would "break" and one that would be "strong"?

Penny: This one (40) breaks and this (43) strong.

Interviewer: Show me how 43 is strong. How do you test for strongness?

Penny: Well, (picks up steel; 43 on steel)-doesn't scratch.

Interviewer: So being strong has something to do with scratching?

Penny: Yes.

Interviewer: Can you show me what (equipment) you used to help you decide on this order?

Penny: Well, fingernail, penny, piece of steel and file (point to and picks up each object).

Interviewer: Why did you decide to use just those objects?

Penny: Well, this (streak plate) you could only tell the color. The streak is ? and this (magnet) doesn't have to do with anything about hardness.

Interviewer: And what about the hammer?

Penny: Well-------

Interviewer: Would that help you solve this in anyway?

Penny: Well------a little.

Interviewer: How?

Penny: If you hit (7), it would probably break and if you hit 43, it wouldn't break very easy----- It's pretty hard.

Interviewer: And, did you use this piece of paper (hardness scale)?

Penny: Yes-to show that the fingernail is the weakest so it would scratch whatever rock was the weakest. And with my fingernail to see which was the weakest and then the copper coin was the second weakest so I scratched the other four to see which was the second weakest.

Interviewer: What happened when you did that-with the copper coin?

Penny: Well, these three (43,40,4) didn't scratch very well, but this one (28) did.

Interviewer: Can you show me how you did that?

Penny: Yes, like this (copper coin on 28).

Interviewer: And lastly you used the file. How come you did it in this order?

Penny: Cause it's softest to hardest.

Interviewer: Could you do something to show that the copper penny is harder than the fingernail?

Penny: Well, if I picked this ((28) my fingernail wouldn't scratch it but the copper penny would. [Assumes copper coin is scratching]

Interviewer: Suppose you didn't have any minerals here. Could you still prove to me that the penny was harder than your finger?

Penny: Um.... Well, your fingernail can break but the copper penny would be real hard to break.

Interviewer: You mean you would do like this (breaking motion) and see if it would break?

Penny: Yes.

Interviewer: Anything else you would do?

Penny: Well----try scratching.

Interviewer: Could you do it? Show me.

Penny: My fingernail scratches it (picks up steel and copper coin; scratches steel on copper coin).

Interviewer: What are you testing now?

Penny: To see which is harder.

Interviewer: What is harder?

Penny: (Uses steel to scratch fingernail.)

Interviewer: You used the steel to scratch the penny and then your fingernail to see which is harder?

Penny: Yah. Well, this one (fingernail) could be scratched. And this one (copper coin) can't. So, that one's (copper coin) harder.

Interviewer: Supposing you just had the penny. Could you now figure out which is harder, the fingernail or the copper coin?

Penny: Um--------.

Interviewer: Is there anything you could do to be able to say, ah hah, the copper coin is harder than the fingernail?

Penny: Well, you could try breaking it.

Interviewer: Anything else you could do?

Penny: ------- ------ I don't know.

Interviewer: O.K. Now suppossng you were out in the mountains and you picked up these five minerals, ---------------. Could you do that?

Penny: Well, the fingernail-------. And I could tell that this (7) is the softest cause it is scratched by my fingernail. I'd probably know by scraping them off. Try to scrape this together (28 and 43). This one got scratched (28 by 43) and then rubs it off (noticing something).

Interviewer: What happened?

Penny: Dust came off.

Interviewer: Off of where?

Penny: Number 43.

Interviewer: Try it again.

Penny: No, ah, numbers 28.

Interviewer: How do you check to tell which one has been scratched? Can you see the scratch in 28?

Penny: Not very good.

Interviewer: What do you think the stuff was that rubbed off?

Penny: --------------

Interviewer: Was it 28 or 43?

Penny: Um---------- (looks at both) -----------
Hmmmmmm----------

Interviewer: What would you decide between those two?

Penny: ------------I think it would probably be 28.

Interviewer: 28 would be what?

Penny: Harder. Softer.

Interviewer: Softer? And then 43?

Penny: Yah.

Interviewer: And these others? How would you test these?

Penny: ---------------

Interviewer: Now, remember you are in the field and trying to determine the hardness of the minerals. How would you decide the hardness of the rest of them?

Penny: I'd use 43.

Interviewer: Why?

Penny: Cause it harder than these (7 and 28). (Scratches 4 with 43; rubs it off) You can sort of see some scratches on here (4) and some parts came off.

Interviewer: Where did the parts come off, 4 or 43?

Penny: I don't know. I'm going to try my fingernail. Maybe 43----

Interviewer: Maybe 43 is?

Penny: Softer.

Interviewer: How come?

Penny: Well, because I tried to use my fingernail and it came off of it.

Interviewer: Now what would you do?

Penny: Probably scratch this (4) with my fingernail (fingrnail on 4). Hard to scratch. This (4) one's (4) probably harder.

Interviewer: So, where would you put that?

Penny: (Scratches 28 with fingernail) Yah, I think this (4) seems harder too.

Interviewer: So, what would be the order now? Are you going to change the order now? What would be the softest one?

Penny: 7. (Points to 40) I'm not sure about this one still. This one's hard to scratch with my fingernail (scratches 40; continues scratching). Well, a little bit was coming off of there but I still think this (43) would be the softest cause a little bit more came off. (Order: 7,43,4,40,28). (Puts 40 next to 43 (7,43,40,4,28); looks at them; pauses-------; finally picks them up).
I'll try and scratch them together. (Rubs off; 28 on 4.) It scratches a little bit.

Interviewer: Is 28 scratched at all?

Penny: No, so I think I'll put this one (4) and then 28.
(Final order: 7,43,40,4,20)

Interviewer: What do you think is better-to use your fingernail or one rock scratched against another?

Penny: -----------

Interviewer: Or doesn't it make any difference?

Penny: The fingernail because if you scratch a rock together your're not sure which one the dust comes off of.

Interviewer: Is there anything else you could do that would tell you which one came off of?

Penny: Try scratch it with a different rock.

Interviewer: And how would that help you?

Penny: Well, if you scratch these two (4 and 28) and dust came off, then you could try this one (4) and some other one and if you scratch two (40 and 43) and stuff came off and you scratched this one (43) with this one (4) or these two together (28 and 4) and a little stuff came off, then try scratch these two (43 and 28) and parts would chip off and there would be scratch on here (43).

Interviewer: So, you would look for a piece that came off plus you'd look for a scratch?

Penny: Um-----um-----.

Interviewer: Could you just tell me once again how you decided on this order 7,28,4,40,43? (original order).

Penny: It's wrong.

Interviewer: Now you think the other way you tested was better?

Penny: Yup. Um----.

Interviewer: How would it happen that you would get this them (different order)?

Penny: Well, I think-----that -----well, when I tried to scratch this (43) parts came off and I scratched this one (28) and nothing came off.

Interviewer: How did you decide that 43 was the hardest before?

Penny: Well, when I scratched this (28) only dust came off and I could rub it off.

Interviewer: If you went back to using your scale, would you change your method?

Penny: Yah.

Interviewer: Show me what you'd do now.

Penny: I'd probably try with the copper penny on (28)---no, scratch-(copper coin on 4)--it would scratch (scratch on 40). A little dust came off. (Copper coin on 43) A little scratch--not much though. Probably this (40) could be next (7,40) and then (copper coin on 28; copper coin on 4;
puts down copper coin and picks up steel; steel on 43). Dust came off - so put 43 next (7,40,43) and then I'd put 28 and 4. (Final order: 7,40,45,28 and 4).

June 10, 1977

Hardness

Bill

Interviewer: (Gives directions)

[Minerals: 7-Talc, 40-Halite, 43-Fluorite, 4-Apatite, 28-Corundum.]

Bill: (File on 43 (1X); touches hammer, then hardness scale; writes on paper.
File on 4 (3X); rubs; writes.
File on 28 (6X); looks; writes;
file on 7 (2X); writes;
file on 40 (2X); file on 4 (2X); looks at 4 with magnifier; writes.
Magnet on 28, 43, 4, 7, 40.
Streak plate: 40 on streak plate and writes; 4 on streak plate, writes; 43 on streak plate writes; 43 on streak plate, writes; 28 on steel, writes; looks with magnifier;
4 on steel, writes; 7 on steel; 28 on steel, writes; 43 on steel, writes; 40 on steel, writes; 28 on steel, writes (looks with magnifier).
Cooper coin on 40, rubs; 40 on copper coin, rubs, writes; 43 on copper coin, writes; 4 on copper coin, rubs, looks, writes; 28 on copper coin (3X), looks with magnifier, writes; 7 on copper coin, writes.
File on 4 (4X), uses magnifier, rubs, looks, files again, rubs again, looks with magnifier;
File on 40 again, looks with magnfiifer; file on 40 again; file on 43, rubs and looks with magnifier).
40 on steel; hammer on 4 (1x); hammer on 40 (4x); hammer on 4 (2x); hammer on 43 (1X); writes. Tries magnet again on all minerals.
File on 28, rubs, looks with magnifier, file on 28 (3X) and 5X on different sides, looks with magnifier; File on 43 (hard scratch), looks, writes.
File on 40, looks with magnifier; 4 on steel; 28 on steel, rubs; 4 on steel; 43 on steel,rubs; file on 43; file on 4; file on 28; looks with magnifier, writes.
28 on steel; 43 on steel, rubs; 28 on steel; 42 on steel - pressing harder; steel on 43; steel on 28; steel on 43 (3X), looks with magnifier; writes in boxes.
File on 40, file on 4; file on 43; file on 28; looks at all with magnifier; steel on 4; steel on 43; steel on 4; steel on 43; steel on 4.)

Discussion

Interviewer: This (exercise) is about "hardness" right?

Bill: Yes.

Interviewer: What does "hardness of a mineral" mean?

Bill: How it can be scratched and how it scratches things.

Interviewer: Anything else?

Bill: --------

Interviewer: Just that?

Bill: Yah?

Interviewer: Can you tell me which objects you used to help determine the hardness?

Bill: Everything, mostly these two - steel and file.

Interviewer: How did the magnet help you determine the hardness?

Bill: Not at all really.

Interviewer: How come?

Bill: Cause none of them were magentic.

Interviewer: It they were magnetic, would that help you?

Bill: I'd probably know what it was then and I might know the hardness already.

Interviewer: So it would give you a clue that way?

Bill: Yah.

Interviewer: And what about the streak plate. How would that help you?

Bill: Well, I think soft rocks would scratch it and none of them scratched it so they're all hard.

Interviewer: Harder than this (streak plate)?

Bill: Yah--this one (7) sort of crumbles. Some of them are clear and doesn't have much colour like this one (7) and (40), so they can't leave a mark.

Interviewer: What about the file? How did that help you?

Bill: Like see how easily they scratched.

Interviewer: And the hammer? How did that help?

Bill: It made a little dent in some of them than in other ones.

Interviewer: How does that help you? What did you look for?

Bill: Scratches or if it just came off in little pieces of it there's a dent.

Interviewer: Then it gives you a clue? ----And the copper coin? How does it help?

Bill: Well, most of them scratch it cause it's so soft, but I can see just how hard they were. They're harder than that (copper coin).

Interviewer: And the piece of steel?

Bill: Yah. That's about the middle thing in hardness so I can kinda tell if things can scratch it and which side was softer or harder.

Interviewer: And you used this scale did you?

Bill: Yup.

Interviewer: How does the scale help you?

Bill: Um, like if it doesn't scratch a copper coin then you know it can't be more than third or second and ......

Interviewer: And how does the scale work?

Bill: By how hard they are to scratch or how easily they scratch something.

Interviewer: When you say "they", what do you mean?

Bill: The fingernail, copper coin, and so forth.

Interviewer: How does the order run here?

Bill: Softest to hardest.

Interviewer: How could you prove to me the steel was harder than the penny?

Bill: Like if I took the steel, it would scratch the penny.

Interviewer: Now, you decided: 7,40,4,43,28. Tell how you did that.

Bill: Well, I wrote it all down here.

Interviewer: You tested each one with the file and steel? How did that help?

Bill: Then I could look back and see what scratched what and how much, how hard, if it scratched it a bit on 40.

Interviewer: And what did that tell you?

Bill: Like, I think that's the penny so it only scratched it a bit, so.....

Interviewer: And the others all scratched it (the three minerals that were left).

Bill: Yah.

Interviewer: How did you decide between those three?

Bill: Well, I just used the magnifier to see how big the scratch was.

Interviewer: Tell me about the bigness of the scratch.

Bill: Like how deep it was and how much it took out and everthing.

Interviewer: That helped you a bit?

Bill: Yah.

Interviewer: And did you do the same thing with steel and file?

Bill: Yah.

Interviewer: And you came to this conclusion (order).

Bill: Yah.

Interviewer: Now, Bill, supposing you were out in the mountains and found these five minerals, ------

Could you do that?

Bill: Not sure. I might - depends on what equipment I have.

Interviewer: You don't have any equipment - just you, and you find these five minerals.

Bill: I don't know. It depends if this (4) scratches this (28). Say 28 scratches 40 and then I know 28 is harder.

Interviewer: Try it. Does it scratch it?

Bill: A bit-not much.

Interviewer: What does that tell you?

Bill: I don't know --------this (28) is probably harder.

Interviewer: How would you figure the other ones out?

Bill: I'd have to scratch them all but I don't think it would work or anything.

Interviewer: Why?

Bill: Because thie one (43) might just scratch this (4) and this one (4) might be able to scratch this one (43) too. They could be just the same.

Interviewer: Why don't you try that.

Bill: (4 on 43.)

Interviewer: Does it scratch?

Bill: Yah, (43 on 4).

Interviewer: How about that?

Bill: A bit - a little bit.

Interviewer: What do you think you'd decide about what you found out here?

Bill: This one (4) is harder.

Interviewer: Could you be sure of any of these?

Bill:	No.
Interviewer:	None of them?
Bill:	No.
Interviewer:	You don't think that would be a very good method?
Bill:	No.

June 8, 1977

Hardness

Gerry

Interviewer: (Gives directions)

[Minerals: 7-Talc, 40-Halite, 43-Fluorite, 4-Apatite, 28-Corundum.]

Gerry: (Looks at all mineral without toughing them. Picks up 7; fingernail on 7 (3X); puts 7 aside; fingernail on 4, 28,40,43; writes in observation space (lines 1 and 2).
Copper coin on 40, 41,; looks at 4; copper coin 43, 28 (scraping motion).
28 on copper coin; 43 on copper coin; 4 on copper coin; 7 on copper coin; 40 on copper coin; copper coin on 4, 40.
Hum. (Fingernail on 7, looks, picks up 4 and puts 4 down immediately. Takes steel; 28 on steel; 40 on steel; 43 on steel (2-3X); works quickly; rubs off each time; picks up magnet; magnet on 40; put magnet down quickly; thinks; looks at minerals; writes (lines 3,4).
(Hardness scale is on top of paper at an angle away from Greg; he doesn't look at it while working.)
Feels steel; puts it down and writes. Copper coin on 28(2X), (3X); looks at it, writes (lines 4,5). Feels 40 (rubbing and turning it around). Picks up hammer and taps 40, 43, 4, 28 (one tap each); writes (lines 5,6). (Fingernail on 43; hammer on 43; fingernail on 7 again; looks at paper; reaches for hammer; tuches hammer, removes hand and picks up file; file on 40; looks at 40; 40 on steel, rubs off; writes; 40 on fingernail; fingernail on 40; writes in bottom right hand corner; thinks; looks and writes -line7).
Fingernail on 7 again; draws line across paper and writes; 7 on fingernail writes. Puts together 43 and a piece which broke while tapping it - matches them. File on 43; steel on 43; writes.
Looks at hardness scale turns it around and continues to write.
Fingernail on 40; copper coin on 40; steel on 40: 40 on copper coin; looks at mineral; picks up 40; holds 40 in hand while writing (bottom right hand corner.
(Fingernail on 28; copper coin on 28; steel on 28; copper coin on 28, rubsv 224 off (5-10X); spends about a minute on it; writes (bottom

right hand corner).
Looks and tries 28 on steel; writes bottom in right hand corner; 40 on steel (2X); 4 on steel; steel on 4; copper coin on 4 (6X); rubs off each time; scratches 4 harder.) Doesn't scratch. (Steel on 40; 40 on steel.) Not hard. (Looks at hardness scale and writes; bottom right hand corner; 4 on steel again; writes. Fingernail on 43; puts 43 aside; rubs 4 and 40; scrapes 40 with fingernail; scrapes 43, 4; hammer on 4 (2X); file on 4; scratches hard; file on 28; looks;) It scratches and it's streaking. (Rubs off, looks; file on 43; picks up 28 and 43, one in each hand, rubbing them back and forth simultaneously; writes.

Copper coin on 43; fingernail on 43; copper coin on 28 and steel on 43 (erases boxes 3 and 5). Feels 28; writes in box. Rubs and scratches 43 with fingernail; steel on 43; copper coin on 43; fingernail on 28.)

Discussion

Interviewer: Now Gerry, this was all about hardness of minerals. Can you tell me everything you know about hardness?

Gerry: You use materials like a hammer and file and stuff to see how hard they are. Like rub against them and see if they'd be scratched. And with the hammer maybe you could hit the rock and see if it would be chippe or anything.

Interviewer: So, are you saying hardness has someting to do with scratching and breaking?

Gerry: Yah.

Interviewer: How are scratching and breaking different?

Gerry: Scratching is like a mark just left and when you break something, a piece falls off.

Interviewer: And how does each of these, scratching and breaking, help you to decide how hard it is?

Gerry: Not too sure about that------

Interviewer: But you used both of them. What did you look for?

Gerry: Whether it could be scratched or whether it scratches the other materials also.

Interviewer: Can you tell me which of these objects you used to help you decide on this order?

Gerry: File and streak plate mostly and the penny and once or twice I used the hammer.

Interviewer: O.K. did you use your fingernail?

Gerry: Yah.

Interviewer: And did you use this harndess scale?

Gerry: Yah.

Interviewer: How did the scale help you?

Gerry: Shows the fingernail is the softest, copper coin is next, and piece of steel and then the file.

Interviewer: How could you prove to me the piece of steel was harder than the copper coin?

Gerry: You can rub them together and see which scratches better (steel on copper coin; copper coin on steel). The steel plate scratches the penny but the penny didn't scratch the steel plate. It showed the steel is hard.

Interviewer: I see you decided on the order of: 7,40,4,43,28. How did you decide on that order?

Gerry: 7 felt quite soft and you could scratch it with your fingernail (bending it while talking).

Interviewer: What do you mean "it felt soft"?

Gerry: It could bend easily and stuff.

Interviewer: Does softness tell you something?

Gerry: How hard it is ---- and the other ones I wasn't too sure about. This one (40) I think I scratched it with a penny (copper coin on 40), but I'm not too sure (looks at paper). Scratch it with a steel plate. Like most of them you can't scratch with a steel, but it chips and comes away.

Interviewer: What does the chipping tell you?

Gerry: That it's soft in some places and it felt a little oily too.

Interviewer: What would oily have to do with being hard?

Gerry: Um, not too sure here if it would have anything to do with it. It just felt oily to me.

Interviewer: Ummmmm---------

Gerry: (Picks up 4) I wasn't too sure about the last three. They felt pretty well the same (scrapes 4 with fingernail).

Interviewer: What do you mean "they felt the same"?

Gerry: Well, they felt the same hardness. They were scratched by the same materials scratched by the penny and the steel.

Interviewer: Scratch-the steel scratches all (43,4,29) of these?

Gerry: I couldn't really tell with this one (28) cause it was so small. It looked like it was being scratched. This one (4) it got scratched a bit, a tiny bit, but on this one (43) I think you can rub it off.

Interviewer: What did that tell you?

Gerry: It's harder but there was a streak - cut in there before. That must mean it's probably the hardest because the steel scratches these two (40,28), but it doesn't scratch this (43).

Interviewer: Can you show me how the steel scratches the others?

Gerry: (Steel on 28) A slight scratch. (Doesn't rub it off.)

Interviewer: What if I do this (rubs it off)?

Gerry: Hmmmm, (steel on 28).

Interviewer: What did you find out?

Gerry: I though it (43) was being scratched but I guess it rubs off. Just maybe chips a bit but now it seems to be scratched a bit ((by the file).

Interviewer: It scratches? What does that mean?

Gerry: That it (43) is softer than the file.

Gerry: It's hard to tell cause it's too dark (file on 28). Can't tell if it's being scratched off or staying.

Interviewer: Do you see a mark on there? A scratch? Try again and look.

Gerry: Maybe a tiny scratch.

Interviewer: So you still think that's the hardest?

Gerry: Yah.

Interviewer: Now, Gerry, supposing you were out in the mountains and you found these five minerals ------. Could you do that?

Gerry: I don't think you could because some them feel quite close and you'd have trouble doing it.

Interviewer: Could you figure any of them out?

Gerry: Yah, probably this one (7) cause it's so soft and it's way softer than the others and maybe this one (40) cause it chips a bit. But none of the others cause they're so close.

June 10, 1977

T17/1

Hardness

Mike

Interviewer: (Gives directions)

[Minerals: 7-Talc, 40-Halite, 43-Fluorite, 4-Apatite, 28-Corundum.]

Mike: Try fingernail on 43. Nope. Let's see what's next. Copper coin (copper coin on 43; 43 on copper coin, rubs.) O.K. Then we go to the piece of steel. (43 on steel; steel on 43, rubs.) Doesn't look like a scratch. (Looks at hardness scale.)
Number 4. Try the fingernail. Not too sure. Try copper coin (top to botoom). Scratches copper coin and steel (4 on steel; steel on 4) and scratches a piece of steel. Try the file (file on 4). It scratches this.
(Looks at equipment) No glass. (Picks up streak plate; 4 on streak plate.) It's hard.
O.K. next 28. (Fingernail on 28.) No, I don't think so. (28 on copper coin; copper coin on 28.)
Scratches the penny. (28 on steel)
Scratches that. (28 on copper coin). File (28 on file, rubs off; file on 28). I think it's harder-- not sure. (28 on streak plate).
O.K. 43. (File on 43; 43 on file, rubs off.) Um---- How about the steel? (43 on steel; steel on 43; rubs off; looks) It scratches. Oh well-----.
(Takes 7; fingernail on 7) That scratches with a fingernail.
(Fingernail on 40) Nope. (40 on fingernail) It scratches my fingernail. Try the penny. (copper coin on 40; 40 on copper coin, rubs off.) Doesn't scratch copper penny.
What about this thing-43? (looks at it and puts it down with 4 and 28) What do you do if it all matches the same thing?

Interviewer: Well, you going to have to figure out if they all are the same hardness. Or maybe you can figure out a test that will tell you (if there is a difference).

Mike: O.K. (43 on streak plate) A few scratches. (Puts streak plate down) Well, take a look. (Looks at 43 with magnifier) Um-----(looks at 28; pauses; picks up 43 and tries file again; 43 on file.) Doesn't scratch that. (Sighs; 4 on file; rubs off) Is there a covering one here cause it scratches here and not here (on file but not on point)?

Interviewer: I don't think so.

Mike: (Sighs; looks at equipment; thinks; picks up hammer) Goodness, hardness - it's (hammer) not scratch. (Puts hammer down; thinks; scratches his chin; picks up 4; fingernail on 4; looks at it; turns 4 around; puts hammer far away; begins to write.
Writes and fills in observation spaces; looks at minerals as he writes; uses magnifier to look at 4; writes; picks up 28; uses magnifier, writes; magnifier on 4 again; uses fingernail; looks at equipment; picks up hammer and bangs 4 slightly; looks; gives it a big hit.
Takes hammer and taps 43 on point (3X); fingernail on 43; hammer on 4; hammer on 43; a piece breaks off 43; examines chips; writes; looks at chips.
Picks up hammer and hits 28 many times, harder and harder; hammer on 4 a few times; examines dust on table; picks up 28 and holds it next to dust) O.K., this one (28) breaks the hardest and then this (4) and that (43) so---(writes). (Periodically looks at minerals and then writes;
Picks up 7; 7 on steel) Oh, boy! (4 on steel; sighs; writes again and fills in boxes.)

Discussion

Interviewer: Can you tell me everything you know about "hardness of minerals"?

Mike: Everything? What do you mean?

Interviewer: What do you think of when you hear the words "hardness of a mineral"?

Mike: ----How easy it scratches.

Interviewer: Anything else?

Mike: How hard it is to break.

Interviewer: Anything else?

Mike: Nope.

Interviewer: What's the difference between scratching and breaking?

Mike: Scratching seems how hard it is on, um, different hardnesses and breaking is how heavy a blow you have to do before it breaks.

Interviewer: I see. You were looking down here sometimes (pointing to dust on table) What were you looking at?

Mike: I broke the table.

Interviewer: Oh my, well, did you ever examine the (mineral) pieces?

Mike: Nope.

Interviewer: The pieces aren't important then?

Mike: (Shrugs shoulders) Nope.

Interviewer: Can you show me the objects you used to help you decide on the hardness?

Mike: Hammer, file, streak plate, steel, penny and fingernail.

Interviewer: Did you use the hardness scale?

Mike: Yes, to tell which was hardest.

Interviewer: Which (object on hardness scale) is the softest?

Mike: Fingnernail.

Interviewer: And the hardest?

Mike: File.

Interviewer: The penny is harder than the fingernail? Could you prove that to me?

Mike: Yah - just scratch it (fingernail on copper coin and copper coin on fingernail).

Interviewer: O.K. and how would you show that the steel is harder than the penny?

Mike: See if it scratches the penny (steel on penny).

Interviewer: O.K. In what way did the scale help you?

Mike: It told which was softest to hardest.

Interviewer: What do you mean which?

Mike: Well, this (fingernail) is softer than this (copper coin).

Interviewer: How did you use it to help you decide on the hardness of minerals?

Mike: I started with this one (fingernail) and if my fingernail scratched it, I would put it here (above fingernail). If it was softer then I went on to copper coin and if it scratched the copper coin I went to the piece of steel and if it scratched the steel, I went to the file and if it scratched the file I went to the hammer to see how it broke.

Interviewer: Would you add the hammer to the list?

Mike: No, because you don't scratch the hammer.

Interviewer: But you still can use it to determine hardness?

Mike: Yah.

Interviewer: Would you like to put the minerals in order according to the order on the paper.

Mike: (Orders them: 7,40,43,4,28)

Interviewer: Can you tell me how you decided on that order?

Mike: I scratched them (points to each one).

Interviewer: What did you find out?

Mike: This (7) could be scratched with my fingernail. This (40) with the copper coin and these ones (43, 4 and 28) I found these could scratch a file.

Interviewer: And did they scratch the steel?

Mike: Yah, they all scratched the file, steel and copper coin.

Interviewer: What happened then?

Mike: Then I wondered. (laughs) No, then I took the hammer and tried to see how hard - to see if they broke -- different blows.

Interviewer: And what happened?

Mike: This one (43) broke the easiest. It went down its plane. And this one (4) broke and this one (28).

Interviewer: What's a plane?

Mike: The angle (motions with hands). THe straight-----.

Interviewer: Where it broke?

Mike: Yah.

Interviewer: Now, Mike, supposing you were out in the mountains and you found thes five minerals, ----------. Could you do that?

Mike: (Sighs; looks) Well---- the fingernail here- could I use it?

Interviewer: Well, I suppose so. You have it with you.

Mike: I'd scratch them all with my fingernail and see which one scratched. And then I'd know this one (7). (puts 7 aside) and then I'd look at them.

Interviewer: What would you look for?

Mike: These - what do you call them? (Points to edges).

Interviewer: You mean the edges?

Mike: Well, you look and see how they look - if it can be cracked through.

Interviewer: So you can tell by looking to see if it would break easily?

Mike: Well, that's not the hardness though. Um---

Interviewer: Anything else you could do to help you detemine the hardness?

Mike: Well, you could scratch each other.

Interviewer: Would you like to show me how that would work?

Mike: (28 on 40) Scratches it.

Interviewer: What does that tell you?

Mike: This one (28) is harder than this one (40).

Interviewer: And then what would you do?

Mike: Try 4 on 40 (does so). It scratches.

Interviewer: What do you know now?

Mike: This one (4) is harder than this one (40). Scratch this one (43 on 40).

Interviewer: What are you going to do now?

Mike: Put this one (4) next to this (7).

Interviewer: What will you do next?

Mike: Well, scratch each other again. (4 on 43; tries a few times). This one (4) scratches this one (43), so it's (43) softer. (Puts 4 down; picks up 28; 28 on 43) It (43) scratches (43) so 28 and 4 would be harder than 43. So, I'd put 43 next to this one (40). (Order: 7,40,43). Try this one. (28 on 4; rubs off; repeats 3X; 4 on 28) They can't scratch each other.

Interviewer: Why not put them down on the table and do it.

Mike: (Tries again; looks; 28 on 4) Don't see anything. (Tries again) Still don't see anything. This one (4) comes off and this one (28) didn't. This one (4) is being scratched.

Interviewer: How can you tell it was being scratched?

Mike: Well, this (4) one's coming off and this (28) isn't. It tells that this (4) can be taken off with this (28), so 28 is harder.

Interviewer: So. what is your order now?

Mike: This one (4) here and this one (28) here. (Order: 7,40,43,4,28).

June 9, 1977

Hardness

Reid

Interviewer: (Gives directions)

[Minerals: 7-Talc, 40-Halite, 43-Fluorite, 4-Apatite, 28-Corundum.]

Reid: First we see what is softest. (23 on steel; fingernail on 43; fingernail on 7) It scratches. (Fingernail on 40; fingernail on 28; puts 7 aside) So far, that guy (7) is the softest.
I'll try the copper coin (7 on copper coin). He doesn't scratch it. (40 on copper coin) Doesn't scratch it. (4 on copper coin) That one scratches. (28 on copper coin) That scratches. (4 on copper coin) It scratches.
Let's see, piece of steel. (43 on steel) That scratches it. (4 on steel) That scratches it. (28 on steel) That scratched it. Oh boy! File next.
(File on 4; rubs) File scratched that. (File on 43) File scratched that. (File on 28) Don't really scratch that.
So, the order is 7,40,4,43 and 28.

Discussion

Interviewer: Reid when we talk about "hardness of mineral" what is meant by that? What do you think of?

Reid: Well, sort of it anything else will scratch it.

Interviewer: Can it mean anything else?

Reid: -------------- Sort of means how easy it will break or how hard it will break.

Interviewer: What do you mean "how hard it will break"?

Reid: Like for instance, what you need to break it.

Interviewer: Like what for instance?

Reid: Well, some you can scratch with your fingernail and others you can hardly break with a hammer.

Interviewer: So, breaking is important for telling the hardness of a substance? ------- Anything else?

Reid: I don't think so.

Interviewer: O.K. can you show me what objects you used to help you determine the hardness of these minerals?

Reid: I used my fingernail, copper coin, piece of steel and file.

Interviewer: And did you use the hardness scale?

Reid: Yah.

Interviewer: How does it work? Can you tell me?

Reid: If your fingernail scratches the rock-the-or-mineral isn't very hard. And if it scratches the copper coin, it, or, no-- like if it doesn't scratch the copper coin, then it's first in the fingernail. If it scratches the copper coin and it scratches the steel then it's in the hardest and its next in line. If it's scratched by a file, it's not really the hardest and if it doesn't get scratched by a file, it's the hardest.

Interviewer: How could you prove to me that the copper coin is harder than your fingernail?

Reid: Cause you can't scratch the copper coin with your fingernail

Interviewer: Can you show me that?

Reid: (fingernail on copper coin)

Interviewer: Oh, yes. Is there another way you could do it?

Reid: Well, you could take another rock.

Interviewer: Yes, but if you just had the copper coin and the fingernail? Can you think of another way?

Reid: ----------No.

Interviewer: O.K., I noticed you didn't use the hammer. How come?

Reid: Cause I wanted to stick to the harndess scale.

Interviewer: And because the hammer wasn't on there you didn't want to use it. But you said that sometimes you break things and that helps tell the hardness.

Reid: Yah.

Interviewer: When would you use the hammer then?

Reid: If you were sort having a problem like if both would be scratched by a thing - like two wouldn't be scratched by a file, then you try and break both with the hammer.

Interviewer: And the streak plate, you didn't use that. How come?

Reid: Didn't really need to know the colour of the rock when you're trying to find out hardness.

Interviewer: And the magnet?

Reid: You don't need to know if it's magnetized or not to find out the hardness.

Interviewer: And the magnifier?

Reid: -------- I would have used it, but I don't think it would do any good.

Interviewer: How did you decide on this order: 7,40,4,43,28?

Reid: What do you mean?

Interviewer: How did you decide 7 was first?

Reid: That's the only one that was scratched by the fingernail.

Interviewer: And 40?

Reid: Cause that wouldn't be scratched by the fingernail, but would scratch the copper coin.

Interviewer: And 4?

Reid: That wouldn't be scratched by the fingernail but would scratch a streak plate and steel, but a file wouldn't scratch it or no - the file would scratch it.

Interviewer: And 43?

Reid: Would scratch steel but still would be scratched by a file.

Interviewer: So, you're saying both 43 and 4 could be determined the same way. Both scratched the steel and they both were scratched by the file. So, how did you decide that 4 came before 43, that 4 is softer than 43 if they both do the same thing?

Reid: I guess I just took a guess.

Interviewer: Did you have a hunch?

Reid: Yah, because the scratch wasn't as deep.

Interviewer: Could you show me that?

Reid: (File on 4) The scratch doesn't go very deep. (File on 43) That one doesn't go quite as deep as that (43 not as deep as 4).

Interviewer: And 28?

Reid: Well, the file wouldn't scratch that one.

Interviewer: O.K. now supposing you were out in the mountains. All you had with you was yourself and you find these five minerals ----------. Could you do that?

Reid: Probably, but it would be kinda hard. First, you would see which one could be scratched by a fingernail and then, um.......

Interviewer: Could you determine any of these with the fingernail?

Reid: You could determine which was the softest.

Interviewer: Which one is that?

Reid: This one (7). And you could find a rock in the woods and test everything on there.

Interviewer: Supposing you just had these four?

Reid: I don't think you could. Well, you could scratch them both together. Like if this one (40) would scratch this one (43), this one (40) would be the harder one.

Interviewer: Could you do that?

Reid: Yah, but this one (4) doesn't scratch this one (43).

Interviewer: Now, you have some evidence, what else would you do?

Reid: So, this one (40) would go there (next to 7). (Order: 7,40).

Interviewer: How do you know that this one (40) isn't harder than some of the others?

Reid: Well, you keep on testing them. (Takes 40 back and tries 40 on 4) Won't scratch that (4 on 40) but scratches that. (4 on 43) Scratch this one. (28 on 43) Scratches it....so both (4 and 28) of these are harder than this (43). (Puts 43 next to 40; order: 7,40,43) And then try both of these (28 and 4). This (28) scratches this (4). (4 on 28) This one (4) doesn't really scratch this one (28), so I'll put this (4) next and then 28. (7,40,43,4,28)

Interviewer: Now compare your orders. What do you think? These two (43 and 4) are different.

Reid: Yah, because they're real close together.

Interviewer: Which one of these orders do you think is more accurate?

Reid: The bottom one (last one).

Interviewer: Why?

Reid: Because you're testing it against rocks. The same rocks, not against other things.

Interviewer: So, if you had to choose the most correct order, would you choose one or two?

Reid: Two.

Interviewer: Do you think you might go back and check these two (43 and 4)?

Reid: Yah, I might.

June 8, 1977

APPENDIX I

Summary Table and Individual Tables Of Testing Techniques Used by Children In Post-Unit Activities

Table A

Tally of Children Observed to Obtain Positive Test Results Upon Application of Various Testing Techniques

Minerals softest to hardest	Positive Results																
	Scratching Techniques									Breaking Techniques						Other Techniques	
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral "Marks" Streak Plate	Number of Pieces	Size of Pieces	Ease of Chipping	Ease of Bending	Amount of Force Required	Hammer Useful	Depth of Scratch	Attracts Magnet
#7 Talc H-1	M M D M T P R c W S G D C	C	c t		C t		C L B t		B M C L T t C				M R S D	c	t M		t C
#40 Halite H-2	M	M G	M M P c W S G D M	B	C c t G	R	R P C L c t	M				P C	R	c	C t T D		B G t C
#43 Fluorite H-5			P c S W M	B R M	M M P G t	M R W S D B R G T c C	B M P C L R c W T S G t R D	M	M C				R	c	M t G	c	B t C
#4 Apatite H-6			C P	M R W S B	R G P t	D T B N M D R C c L R W S G R	B M D R C L R W T S D t P G		R				R		M C t W B		W B t L
#28 Corundum H-9			P C S	B M R R W S	G	B D C R L R c W S G D M T	B N D W	M					R		W		W L B C

Note. B=Bill; c=Candy; C=Chuck; D=Dan; D=Darla; G=Gerry; L=Laura; M=Mike; M=Marlene; N=Nan; P=Penny; R=Reid; R=Roy; S=Sam; t=Tim; T=Tony; W=Wanda.

Table B

Testing Techniques Considered and Used
by Bill in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																					
	Scratching										Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	x			x	x	x	x		x	1 x	1	1		1		1	x		x			2
In-Between				1	1											1						
Hardish										2	2			2		2	1		1			1
Disagree																						

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table C

Testing Techniques Considered and Used
by Candy in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																					
	Scratching										Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	1 x		x			x	x				1			1		2	2				1	1
In-Between			1	1																		
Hardish						1					2			2		1	1				2	2
Disagree										3									3			

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table D

Testing Techniques Considered and Used by Chuck in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																					
	Scratching										Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	X 1	X 1	X	X	X	X	X		X	X 1	1	1	1	1	X		2		X			1
In-Between			1			1				1			2									2
Hardish							1			2	2	2	2	2			1					
Disagree																			3			

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table E

Testing Techniques Considered and Used by Dan in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																					
	Scratching										Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	1 x		x			x	x							1	1	2					1	2
In-Between	2					1																
Hardish	2						1							2	2	1						1
Disagree																						

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table F

Testing Techniques Considered and Used
by Darla in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																					
	Scratching										Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	X 1	X	X	X	X	X	X		X	X 1	X 1	X	1	1	1	1	2					
In-Between			1			1																
Hardish							1			2			2	2	2	2	1					
Disagree																			3			

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table G

Testing Techniques Considered and Used
by Gerry in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																					
	Scratching										Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	1	x	x	x	x		x 2	x					1	1	1		2					
In-Between			1	1	1	1																
Hardish	2						1								2		1					
Disagree																						

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table H

Testing Techniques Considered and Used by Laurie in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																					
	Scratching										Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	1^{x}		x			x	2^{x}			2^{x}					1	2	2		2^{x}			1^{x}
In-Between			1			1																2
Hardish	2						1				2	2			2	1	1		1			2
Disagree																						

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table I

Testing Techniques Considered and Used by Marlene in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																					
	Scratching										Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	1 x		x			x	x			1 x		1	1 x		1		2					
In-Between			1			1																
Hardish	2							1		2		2	2		2		1					
Disagree																						

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table J

Testing Techniques Considered and Used
by Mike in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																					
	Scratching										Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	x 1	x 1	x	x	x	x	x				1			1			2					
In-Between			1	1	1	1						1		1 2								
Hardish							1	1			2	2		2			1					
Disagree											3	3										

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table K

Testing Techniques Considered and Used
by Nan in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																						
	Scratching											Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	1 x		1 x	x	x	x			x	1 x	1 x			1								
In-Between					1	1	1															
Hardish								1		2	2			2								
Disagree																						

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table L

Testing Techniques Considered and Used
by Penny in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																					
	Scratching										Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	1 X	X	X	X	X		X		X	1	1		1	1			2					
In-Between			1		1												1					
Hardish							1			2	2		2				1					
Disagree																			3			

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table M

Testing Techniques Considered and Used by Roy in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																							
	Scratching										Breaking									Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	X	X		X		X	X		X				1 X	1 X	1 X	1 X	2					1 X
In-Between				1		1																
Hardish							1								2	2	1					
Disagree										3									3			

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table N

Testing Techniques Considered and Used by Reid in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																					
	Scratching										Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	x 1			x		x	x									1	2					
In-Between				1		1																
Hardish	2						1									2	1					
Disagree										3									3			

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table O

Testing Techniques Considered and Used
by Sam in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																							
	Scratching										Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	x 1		x	x		x	x		x	x 1	1	1	x 1		x 1	1	x 2					
In-Between	1		1	1		1																
Hardish							1	1	1	2	2	2	2		2	2	1					1
Disagree																					3	

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table P

Testing Techniques Considered and Used by Tommy in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																					
	Scratching										Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	1x				x		2x			1x			1	1			2x		1			1
In-Between					1																	
Hardish	2						1			2			2	2			1		2			2
Disagree																						

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table Q

Testing Techniques Considered and Used by Tim in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																					
	Scratching										Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	1 x		x	x	x		x		x	1 x	1	1	1 x	1	1 x		2		x			1
In-Between			1			1																
Hardish							1		1	2	2	2	2	1			1		1			2
Disagree																						

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

Table R

Testing Techniques Considered and Used by Wanda in Determining Hardness of Minerals

General Categories of Mineral Hardness	Testing Techniques																					
	Scratching										Breaking								Other			
	Fingernail (H-2½) Scratches Mineral	Mineral Scratches Fingernail (H-2½)	Copper Coin (H-3½ to 5) Scratches Mineral	Mineral Scratches Copper Coin (H-3½ to 5)	Steel (H-5½ to 7) Scratches Mineral	Mineral Scratches Steel (H-5½ to 7)	File (H-6½ to 8) Scratches Mineral	Mineral Scratches File (H-6½ to 8)	Mineral Scratches Glass	Mineral "Marks" Streak Plate	Many Pieces	Small Pieces	Chips Easily	Little Force Required (Hammer)	Malleable	Deep Scratch/Dent	Hammer Required	Large Scratch	Attracts Magnet	Melts First	Displays Cleavage	Other
Softish	1 x		x			x	x			1 x	1				1	1	2 x		x		1	1
In-Between		1			1	1																
Hardish	2						1			2	2			1		2	1				2	2
Disagree																						

Note. 1 = said technique was useful

2 = said technique was not useful

3 = said technique was not applicable

x = used technique

APPENDIX J

Excerpt of an Interview with A Professional Geologist

Excerpt of an Interview with a Geologist

(Testing Mineral 29 - Asbestos)

Geologist: Once again there is more than one mineral present here and furthermore there is more than one variety of a particular mineral present which is going to confuse somebody. You have this Asbestiform Serpentine forming these bands here and in between the bands you have some fairly massive Serpentine which will be Lizardite or Antigorite whereas this (white) is Chrysatile. These incidently will have similar hardnesses. It would be almost impossible to test the hardness of the Chrysatile because what you are doing is simply disaggregating the fibrers. The individual fibers are extremely fine-grained and so all you do when you do this (scrape it) is that you actually disaggregate the fibers. You haven't proved anything. You haven't proved that you actually scratched the fibers themselves. However, this material here (black) has the same composition and you can see that the file does in fact scratch this. Can be scratched by a file and can be scratched by a nail and can't really be scratched by a copper coin. Of course, I can scratch this stuff (fibers) with a copper coin. Knowing what I know I wouldn't scratch that but a child might. Should I record it as a child would or as I would?

Interviewer: Just as you would. I'm recording the fact that you said these would be problems for the children.

Geologist: And now for 27 (Microcline). There are two minerals in speciman 27; Feldspar and Quartz are present. Assuming that we will be talking about the Feldspar which makes up the bulk of the speciman here - the pink stuff. O.K. It can't be scratched by that file. Files you realize vary quite significantly in hardness from one file to another. Will scratch glass- Yes, that is true. This won't scratch (steel). Oh, yes it does. This particular piece of steel is harder than the file. Certainly it can scratch a copper coin. The Quartz (white) in here can't be scratched by a nail or by a file.

(Testing Mineral 36 - Tourmaline)

Let's assume we're talking about the pink. The pink mineral will scratch glass. Will be scratched by a file (scrapes it). (Uses proper techniques at all time; rubs off after each scratch attempt; uses magnifying glass to look for scratches.) The black part is very brittle of course. Appears to be a single crystal. I'd put 36 (b) here (next to file). Seems to scratch the glass but I have to be careful that I'm not testing with the Feldspar (pink). This is a test one normally would carry out under a binocular microscope. Now I'm unable to get this into a position that I can tell. I can't tell whether I'm scratching it with one or the other.

Interviewer: It would easy to make a mistake there?

Geologist: Yes. Can be scratched by a file? Yes. Scratched by a nail? Yes. By a copper coin? Not really (tests it; some chips break off).

Interviewer: Is any breaking off?

Geologist: Yes. What I would rather do (black) where it is very brittle and cleaved like this is to put the edge of the copper coin to the material and see if the material is scratching the coin.

Interviewer: Have you ever noticed university students making a error when testing minerals in this sort of situation - where something breaks off?

Geologist: Many times.

Interviewer: What do you think they are thinking which makes them come up with that conclusion?

Geologist: They usually say it's softer than the instrument they're scratching it with.

Interviewer: Where are they making the error?

Geologist: Well, the mineral may have a very good cleavage and it may be fractured already. If they could test it on a completely unfractured material on a clear surface, it wouldn't scratch. But because the material is already broken before they get it, what they are doing is disaggregating the broken fragments.

Interviewer: Are they applying a breaking criterion rather than a scratching criterion?

Geologist: I think the essential thing to remember is that in one case damage is already been done to the material before they got it. In a sense you are breaking something when you scratch it. Of course it's the force you use - like taking a sledge hammer to a diamond. You're going to get a pounder despite the fact that the diamond is harder than the sledgehammer in terms of scratching hardness. In the early days of mineral exploration in South Africa there were a lot of very good diamonds lost because people knew that diamonds were the hardest substance known to man. They would put a diamond on a rock and take a hammer to it and smash it to smithereens. (Doesn't order the minerals)

Interviewer: Could you order the minerals?

Geologist: (Begins to do it in his head and does not look at the table).

Interviewer: Could you order them just using the information in the table?

Geologist: O.K. on the basis of that table (orders them).

January 26, 1978

APPENDIX K

Classroom Quizzes and Tests

Quiz 1 Hardness

(1) List the tests we used for hardness in order from softest to hardest.

____

____

____

____

____

(2) Write the following mineral sample numbers in order of hardness from softest to hardest.

#1. Scratches a copper coin but a steel nail scratches it.

#2. Scratches a steel nail but not a steel file.

#3. Scratches glass.

#4. Can be scratched with a fingernail.

#5. Scratches fingernail but not a copper coin.

#6. Can be scratched by glass but not by a steel file.

____

A Scratches a steel file and scratches glass.

B Steel nail does not scratch it but a steel file will.

C Can scratch a fingernail but copper coin scratches it.

D Scratched by a steel nail but not by copper coin.

E Scratched by glass but not by steel file.

____

Quiz 2 Rocks and Minerals

(1) (a) What is the streak of a mineral?

____

____

(b) Describe how you would determine the streak of a mineral.

____

____

(c) Why do some minerals not leave a streak?

____

____

(2) (a) Circle the best answer:

The hardness of a mineral is

(i) its ability to resist scratch

(ii) the ease with which it breaks

(iii) related to the number of pieces it breaks into when hit with a hammer

(b) The hardest mineral is __________.

(c) The mineral that is #1 on the hardness scale is __________.

(d) If mineral A is scratched by a quartz crystal and mineral B is not, then ______ is harder than ______.

(e) Arrange these minerals in order of hardness from softest to hardest.

Mineral A will scratch glass

Mineral B will scratch your fingernail but not a piece of copper.

Mineral C will scratch a stell file not not glass

Mineral D will scratch copper but not a steel nail

Mineral E will not scratch your fingernail

Mineral F will scratch a steel nail but not a steel file.

____

(3) (a) Using lustre, minerals can be separated into two main groups according to whether the luster is __________ or __________.

(b) Galena and fool's gold have a __________ lustre.

(c) Halite, quartzite and mice have a __________ lustre.

(d) How do you distinguish the lustre of a mineral?

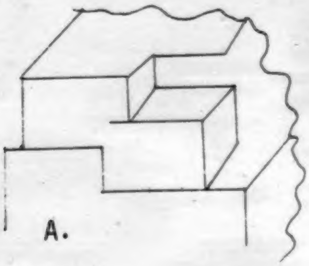
____

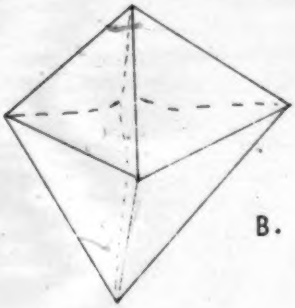
____

(4) (a) What is meant by cleavage when referred to a mineral?

____

____


A.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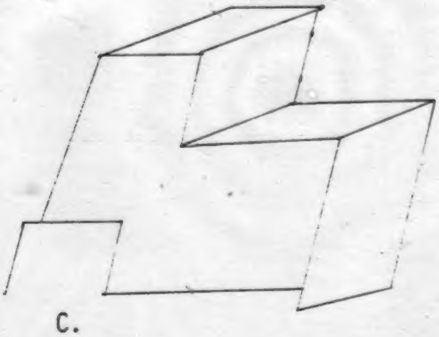
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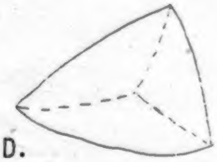
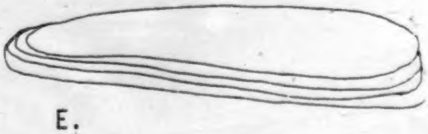

D.


E.

What shape cleavage is each of the following:

quartzite _____ mica _____

fluorite _____ calcite _____

halite _____ galena _____

(c) When trying to determine the cleavage of a mineral, what do you look for?